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16. Abstract

Among the many issues surrounding motor vehicle size and weights, specifically an increase in truck size and weights, is the concern of the impact any change would have on the operational characteristics of rural highways. Today's highway network in any given area is the result of an evolutionary process representing among other things a mix of geometric design principles and practices. Any significant change in the vehicular operating characteristics should require an assessment of the geometric design practices and the impact on the existing highway system in terms of operational aspects and safety. Also needed would be an estimate of the cost required to redesign and modify the current network or segments of the network to accommodate the larger vehicles.

This report represents one element of an ongoing study to assess the various issues and effects of an increase in truck size and/or weights on the rural highways in Texas. The purpose of this report is to summarize a study of the effects that an increase in legal truck limits would have on highway geometric design elements, and the cost implications, should various segments of the Texas highway system require redesign and modification to facilitate their safe and efficient operation.

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PREFACE

This is an interim report on Research Project 3-8-78-241, "Truck Use of Highways in Texas." This report represents one element of an ongoing study to assess the various issues and effects of an increase in truck size and/or weights on the rural highways in Texas. A joint interim report, 231-Interim, "Effects of Heavy Trucks on Texas Highways," was published in September 1978.

Several persons contributed to the preparation of the study reported herein. The authors would like to express appreciation to the following for their assistance: Ben Barton, Harold D. Cooper, Robert L. Mikulin, Gerald B. Peck, and Dan Williams of SDHPT; Dock Burke of TTI; and Paul Ng, J. Wesley Smith, and Chien-Pei Yu of CTR.

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ABSTRACT

Among the many issues surrounding motor vehicle size and weights, specifically an increase in truck size and weights, is the concern of the impact any change would have on the operational characteristics of rural highways. Today's highway network in any given area is the result of an evolutionary process representing among other things a mix of geometric design principles and practices. Any significant change in the vehicular operating characteristics should require an assessment of the geometric design practices and the impact on the existing highway system in terms of operational aspects and safety. Also needed would be an estimate of the cost required to redesign and modify the current network or segments of the network to accommodate the larger vehicles.

This report represents one element of an ongoing study to assess the various issues and effects of an increase in truck size and/or weights on the rural highways in Texas. The purpose of this report is to summarize a study of the effects that an increase in legal truck limits would have on highway geometric design elements, and the cost implications, should various segments of the Texas highway system require redesign and modification to facilitate their safe and efficient operation.

KEY WORDS: geometric design, truck/trailers, truck laws and regulations, rural highways, upgrading, cost analysis

SUMMARY

A set of issues surrounding the legal limits to sizes and weights of motor vehicles has become a primary policy concern of government and the affected industry. Such concern is reflected by current Federal initiatives (stemming from the Surface Transportation Act of 1978), related study activities, and actions of several State transportation agencies.

This report contains an assessment of the range of implications that increased truck size and weight changes would have on rural highways as it relates to geometric design (and redesign) practices and principles. This study represents one element of a broad set of issues surrounding the legal size and weights of motor vehicles, principally trucks. It is intended that this study coupled with other on-going studies in Texas and elsewhere will assist in developing the necessary data on which future decisions can be founded.

Four alternative scenarios were developed to provide a framework for analyzing a significant change in truck dimensions and weight patterns. Scenario A represents the current status and assumes that these weight and dimension limits will remain the same over the twenty-year analysis period. The other three scenarios represent an array of changes in gross vehicle weights, single axle weights, tandem axle weights, lengths, and widths.

Six different vehicle combinations and two highway classification schemes are considered in this phase of the continuing study of "Truck Use of Highways in Texas."

Assuming that either one of scenarios B, C, and D is implemented the reasoning and assumptions made to establish the effect of these scenarios on the design elements, cross section elements, and intersection design elements are reasonable, then expectations are cited regarding sight distances, pavement widening on curves, critical lengths of grades, lane and shoulder widths, and other related elements.

It was concluded that if any one of scenarios B, C, and D were implemented, some alterations to the Texas Highway network may be necessary. An

estimated cost to modify or upgrade the current highway system for each of the scenarios is provided.

IMPLEMENTATION STATEMENT

This report deals with one element (geometric design/redesign) of the ongoing study to assess the various issues and effects of increased truck size and/or weights on the rural highways in Texas. It should therefore be used in concert with previous and/or subsequent reports as a guide in the consideration of the realism of issues surrounding vehicle size and/or weight limits. Although the upgrading costs for some road classes are substantial, there is little difference between scenarios. The findings of this report will therefore assist with the final cost estimation should any one of the scenarios be considered for implementation. It will also be a guide as to the practicality of allowing vehicles of increased size and/or weights on the different road classes and/or systems in Texas.

DEFINITION OF TERMS AND ACRONYMS

AASHTO	The American Association of State Highway and Transportation Officials (formerly the AASHO: the American Association of State Highway Officials)
CTR	Center for Transportation Research
FM	Farm-to-Market Roads
GVW	Gross vehicle weight
HP	Horsepower
HPMS	Highway Performance Monitoring System
SDHPT	The Texas State Department of Highways and Public Transportation
SQRT	Square root

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CHAPTER 1. INTRODUCTION

1.1. BACKGROUND

Legislatures have the responsibility of continually reviewing and revising as deemed appropriate the statutes pertaining to the legal limits of motor vehicle weights and dimensions.

Changes in the legal limits will have an impact on such diverse activities and practices as vehicle design, highway design, highway usage, and the economic vitality of the state. Therefore consideration must be given to all aspects before a decision regarding legal limits can be reached.

The decision making process is made even more difficult for the legislatures because of the absence of a clear definition of the effects that their decisions will have on these activities.

The Legislature of the State of Texas through the State Department of Highways and Public Transportation recognized the need for a clear definition to assess the impact of its decisions on the design of highways, on the upgrading of the roadway should changes be implemented, and on the management of the state's road network. This work is part of a project entitled "Truck Use of Highways in Texas" and is an ongoing research effort that assists the SDHPT in this process. This project is being conducted at the Center for Transportation Research of The University of Texas at Austin in cooperation with the Texas Transportation Institute of Texas A&M University and the Texas State Department of Highways and Public Transportation.

This report documents research that was performed as a part of Project 241. In this effort emphasis was placed on the effects that an increase in legal limits will have on geometric design elements, and the cost implications should sections of the state's road network be geometrically upgraded to allow for the operation of vehicles with increased dimensions.

1.2. OBJECTIVES

The objectives included the following:

(1) To critically review past and current research relating to the consequences of a possible change in legal vehicle dimensions and weights on the geometric design elements of rural roads.

(2) To identify the geometric elements that will be affected by a change in legal vehicle dimensions and weights.

(3) To determine the effects of a change in legal vehicle dimensions and weights on these elements for different operating conditions.

(4) To derive a cost estimate on the upgrading of road sections. This is to ensure that existing operating conditions be maintained should a change in legal vehicle dimensions and weights be implemented.

1.3. SCOPE

Throughout the project four different vehicle combinations and two highway class combinations were considered. The four vehicle scenarios are diagrammatically represented in Figs 1 and 2. First, the three administrative rural highway systems are considered in the analysis. This is the traditional classification of highway systems by route type:

(1) Interstate highway system,

(2) US and State highway system,

(3) Farm-to-Market road system.

Secondly, the following rural functional classes, or combination of classes, are also considered in the analysis. This classification is based on road usage:

(1) Interstate highway system,

(2) All principal arterials (including Interstate),

(3) "All systems" combination, which is a combination of all the following classes: Interstate, other principal arterials, minor arterials, major collectors and minor collectors excluding country roads that may be part of the above.

It was desirable to examine highway upgrading costs according to the above rural systems as the usage, the design standards, and vehicle composition differ.

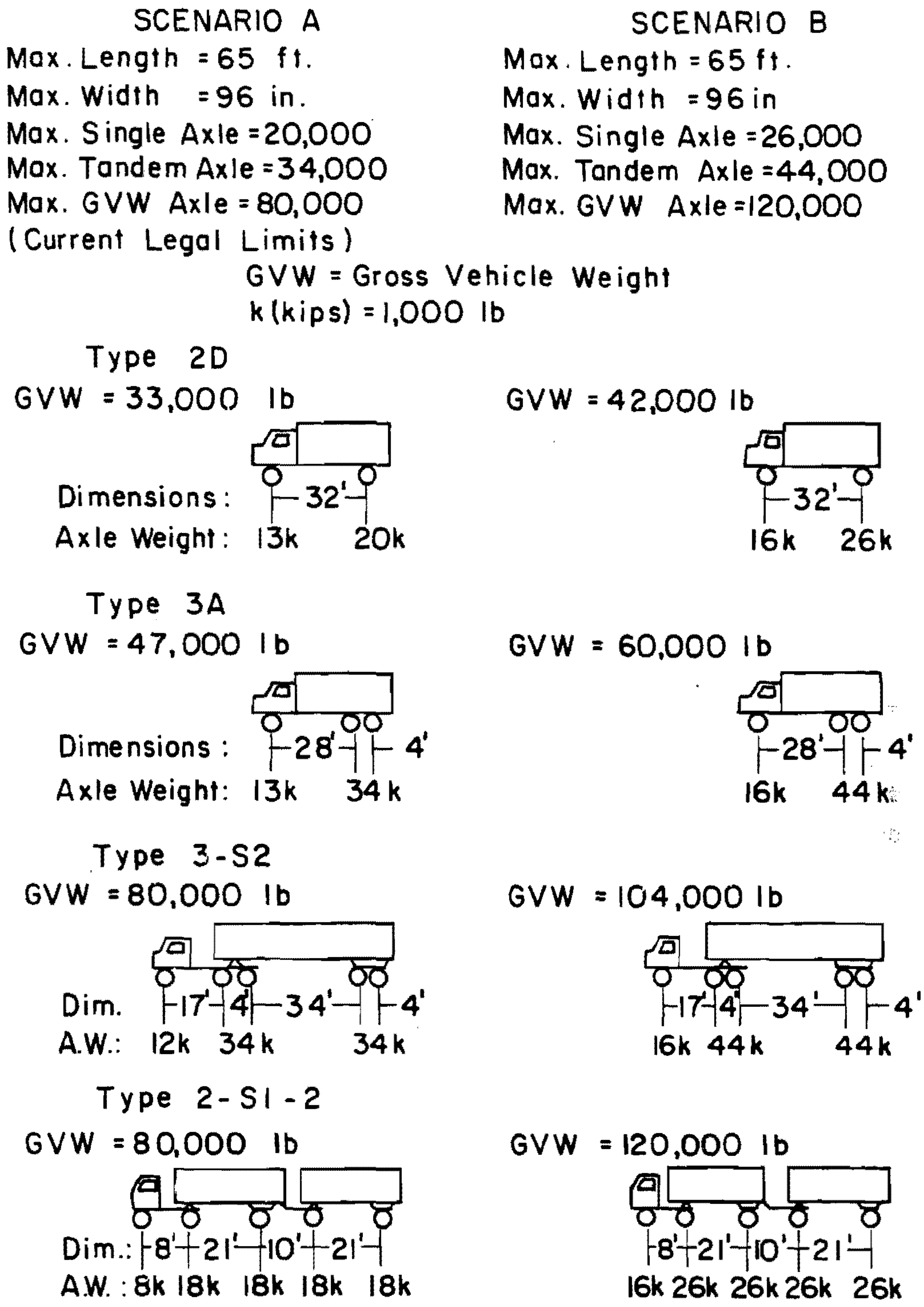


Fig 1. Vehicle configurations for scenarios A and B (Ref 5).

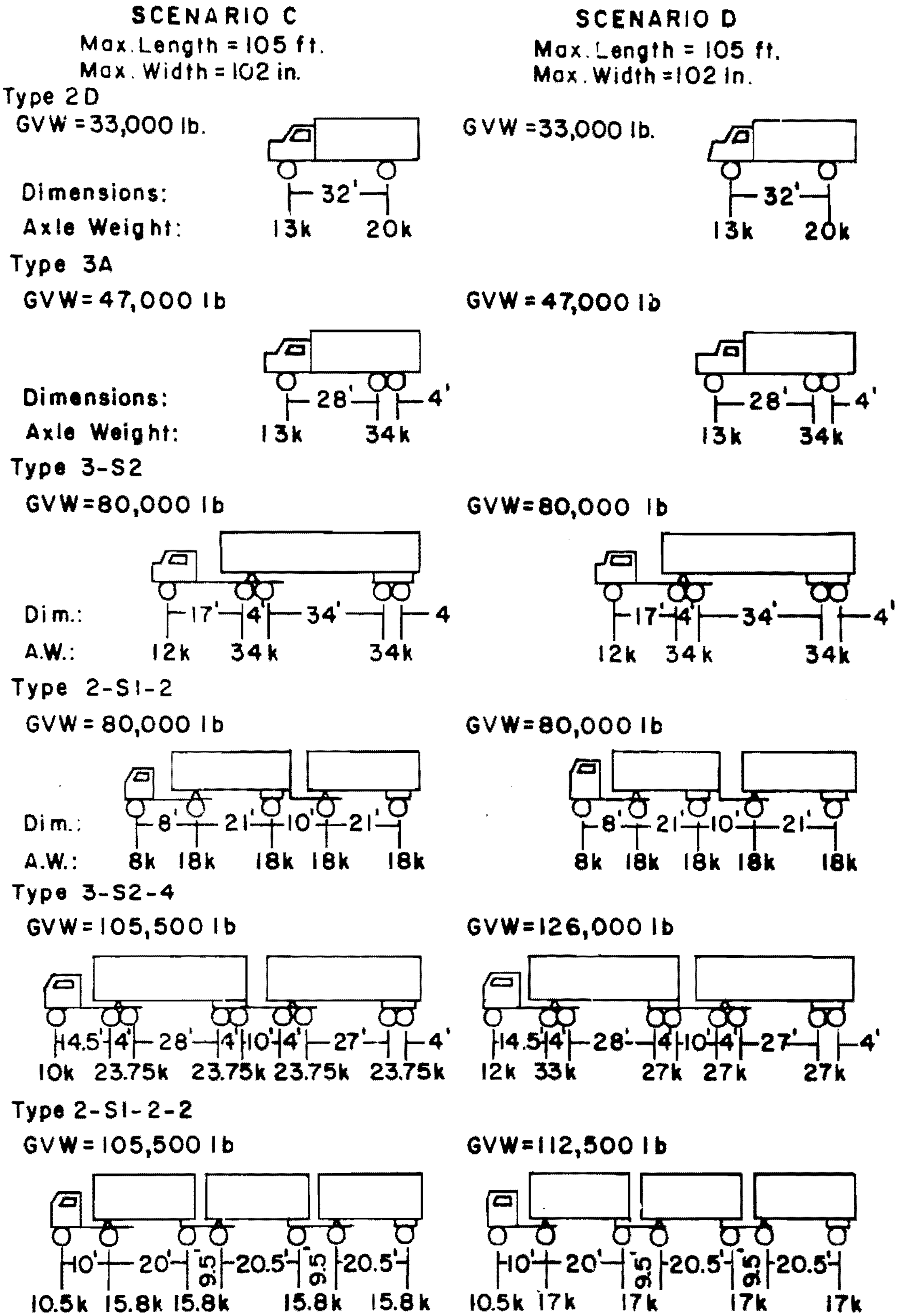


Fig 2. Vehicle configurations for scenarios C and D (Ref 5).

Note that urban, county and local roads were excluded from the analysis.

Four alternative scenarios were developed to provide a framework for analyzing a significant change in truck dimensions and weight patterns. Scenario A represents the current statutes and assumes that these weight and dimensions limits will remain the same over the twenty-year analysis period. The other three scenarios represent an array of changes in gross vehicle weights, single axle weights, tandem axle weights, lengths, and widths.

The scenarios are hereafter referred to as scenario A, scenario B, scenario C, and scenario D. They have the following characteristics:

Scenario A (see Fig 1):

Maximum length = 65 feet
Maximum width = 96 inches
Maximum height = 13.5 feet
Maximum weight = 80,000 pounds (GVW)

Scenario B (see Fig 1):

Maximum length = 65 feet
Maximum width = 96 inches
Maximum height = 13.5 feet
Maximum weight = 120,000 pounds (GVW)

Scenario C (see Fig 2):

Maximum length = 105 feet
Maximum width = 102 inches
Maximum height = 13.5 feet
Maximum weight = 105,500 pounds (GVW)

Scenario D (see Fig 2):

Maximum length = 105 feet
Maximum width = 102 inches
Maximum height = 13.5 feet
Maximum weight = 126,000 pounds (GVW)

1.4. ELEMENTS

The following design, cross section, and intersection elements may be affected by a change in vehicle dimensions and weight.

Design elements

(1) Stopping sight distance

(2) Passing sight distance

(3) Pavement widening on curves

(4) Critical lengths of grades

(5) Rest areas

Cross section elements

(6) Lane width

(7) Width of shoulder

(8) Guardrails

Intersection design elements

(9) Minimum design for sharpest turns

(10) Width for turning roadways

(11) Sight distance at grade intersections

(12) Median openings

(13) Median lanes

CHAPTER 2. DESIGN ELEMENTS

2.1. STOPPING SIGHT DISTANCE

(A) Design stopping sight distance is, according to AASHTO (Ref 3), "The minimum distance required for a vehicle travelling near the design speed to stop before reaching an object in its path."

The minimum stopping sight distance is calculated according to the following formula (Ref 3):

$$SSD = 1.47*V*2.5 + V*V/30(f + \text{or} - g)$$

where

SSD = stopping sight distance,

V = vehicle speed in miles per hour,

2.5 = value assumed to represent the perception and reaction times (sec.),

f = coefficient of friction between the tires and the roadway surface, and

g = percent grade divided by 100.

The first part of the formula (1.47*V*2.5) gives the distance travelled during perception-reaction time. The second part (V*V/30(f + or - g)) gives the distance required to stop after brake application.

When measuring stopping sight distance the following assumptions are made by AASHTO (Ref 3): first, that the height of the operator's eye is 3.75 feet above the road surface; and second, that the operator must detect an object with a height of 6 inches in his path (Ref 3).

The above minimum stopping sight distance formula and measuring criteria were derived for passenger car operation. But AASHTO (Ref 3) states that although trucks require a longer stopping distance for a given speed the additional braking distance is balanced by a higher truck operator eye position. The U.S. DOT, FHWA "Motor Carrier Safety Regulations" specity deceleration rates in feet per second for truck combinations of 14 ft/sec/sec, and for passenger cars of 21 ft/sec/sec. This indicates that cars should stop in two-thirds the distance required for trucks (Ref 15).

(B) The expected performance of trucks due to an increase in weight, will be discussed under the design element "Critical lengths of grades." From this discussion it will be seen that due to superior transmissions and high torque rise engines (Ref 24), the availability of big engines (Ref 6), and a decreasing horsepower to weight ratio (Ref 24), the expected performance of trucks in scenarios B, C, and D will be better than that of the national representative truck of the past.

The coefficient of friction between the tires and the roadway f is also dependent on the wheel load and vehicle momentum. The coefficient of friction plays a critical role in the stopping sight distance as can be seen from the aforementioned formula. Full-scale tests have been conducted by California, Utah, and the Province of Alberta, Canada, on trucks with GVW of up to 108,000 lb to assess the braking performance (Refs 15, 16, and 17). Figure 3a shows the results obtained by the above agencies, while Fig 3b shows the AASHTO and DOT requirements as well as the results obtained by Utah on pavement with a dry $\mu = 0.92$ and a wet $\mu = 0.64$ (Refs 3, 15, and 20). All the dry pavement results in Fig 3b are well under the DOT curve. Stopping sight distances are shown in Table 1.

A theoretical evaluation was performed by IIT Research Institute (Ref 9) and their results, based on analytical studies, computer simulation, and examination of experimental data, confirmed the results obtained by California, Utah, and Alberta.

Maximum vehicle height remains the same for the four different scenarios and no change in operator eye height is expected. This will therefore have no changing effect on stopping sight distance.

(C) If any one of scenarios B, C, or D is implemented, no change in desirable reaction and perception distance or braking distance is expected. Therefore the desirable stopping sight distances as recommended by AASHTO should remain the same.

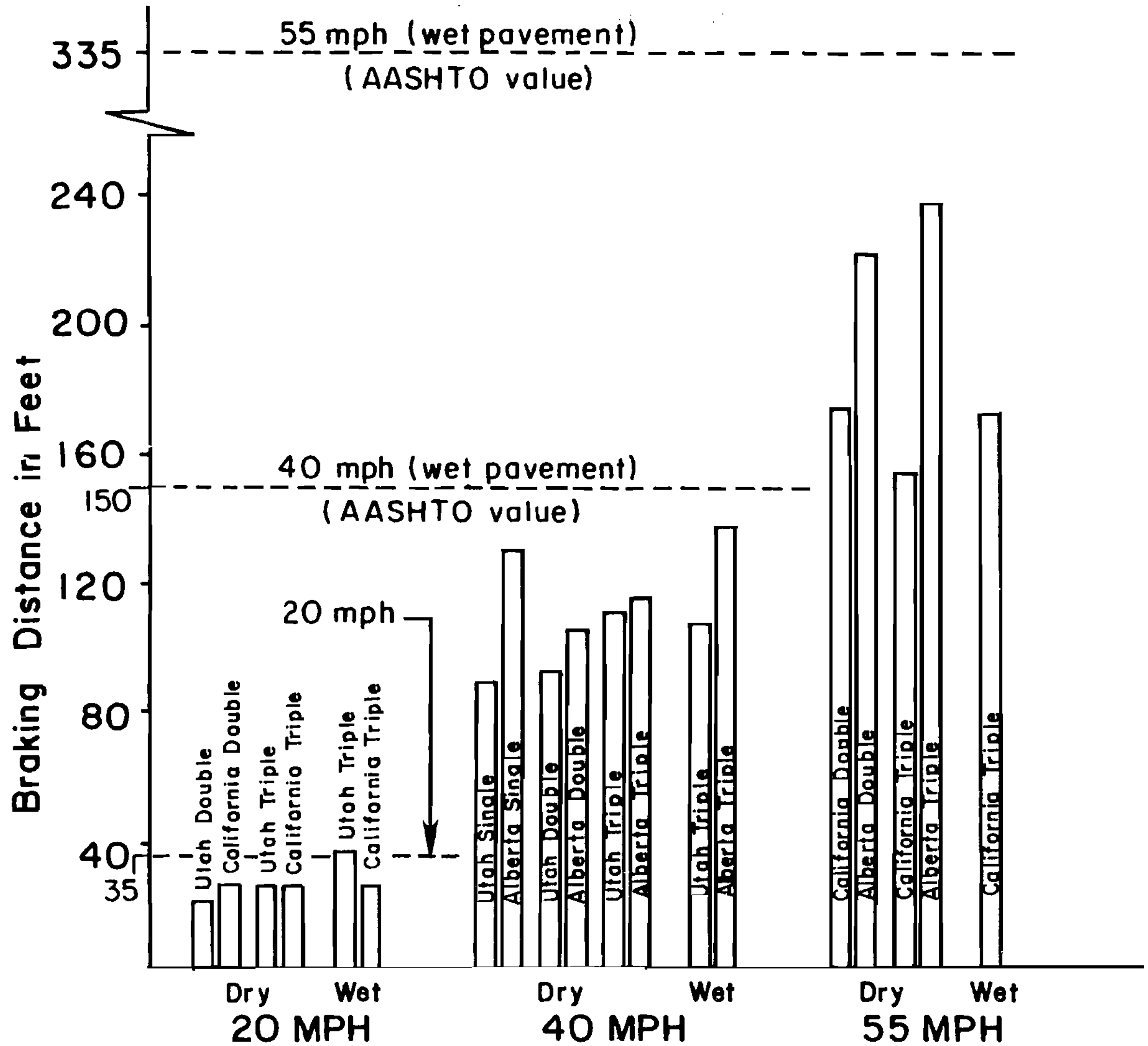


Fig 3a. Braking distance (Ref 15).

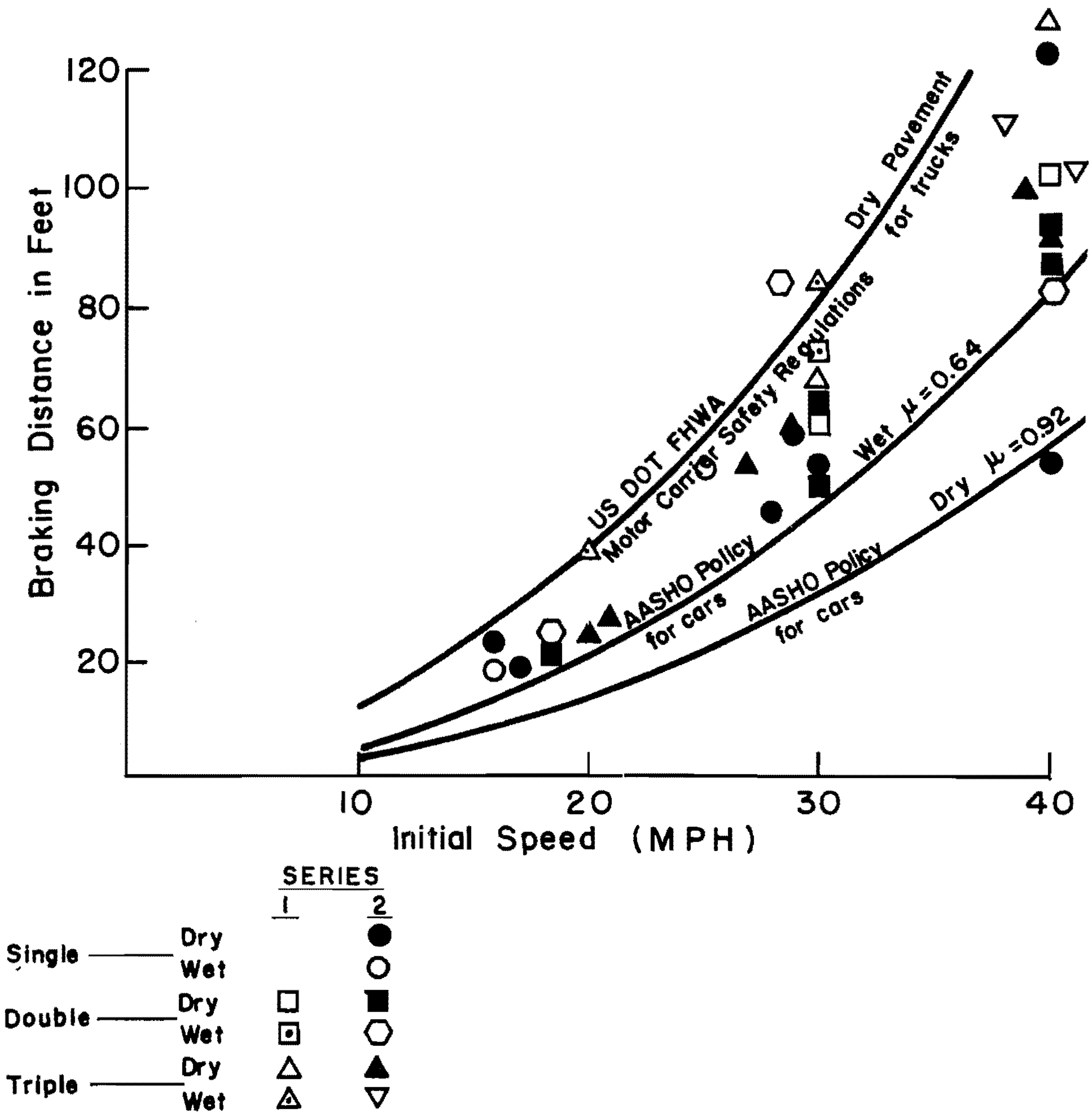


Fig 3b. Braking distance (Ref 15).

TABLE 1. AASHTO STOPPING SIGHT DISTANCES
(REFS 2, 3, AND 20)

Design speed, mph	30	40	50	60
Minimum SSD (ft)	200	275	350	475
Desirable SSD (ft)	200	300	450	650
Reac. + perc. time	2.5	2.5	2.5	2.5
Distance (ft)	110	150	185	220
Minimum fric. coef.	0.36	0.33	0.31	0.30
Desirable fric. coef.	0.35	0.32	0.30	0.29
Minimum braking distance (ft)	75	130	210	300
Desirable braking distance (ft)	90	150	265	430

2.2. PASSING SIGHT DISTANCE

(A) AASHTO states that while most rural highways are two-lane highways, vehicles must frequently use a lane regularly used by opposing vehicles in order to overtake slower moving vehicles. Passing sight distance is the length needed to safely complete this passing maneuver on two-lane highways (Ref 3), with an operator eye height of 3.75 feet and an object height of 4.5 feet.

$$\text{Passing sight distance} = d(1) + d(2) + d(3) + d(4) \quad \text{(see Fig 4)}$$

where

d(1) = initial maneuver distance (feet) and

$d(1) = 1.47*t(V - m + a*t_1/2)$ (Ref 3) where

t_1 = initial maneuver time (seconds),

V = average speed of passing vehicle (mph),

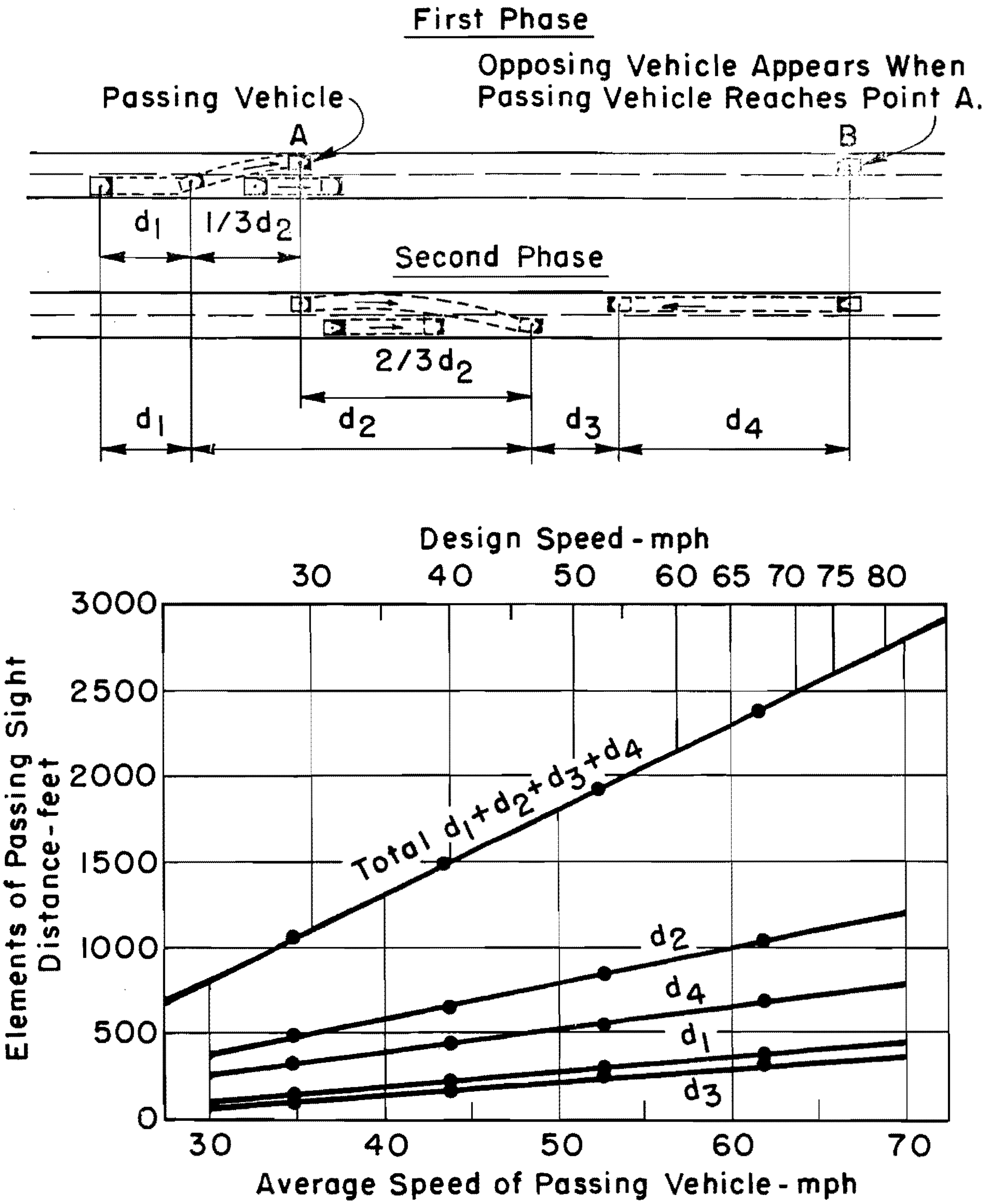


Fig 4. Passing sight distance (Ref 3).

m = speed difference between the two vehicles (mph),

a = average acceleration (mph);

d(2) = distance travelled in the left lane (ft) by the passing vehicle -

d(2) = (Lf + Ls + 150)*V/Vi where

Lf = length of faster vehicle (ft),

Ls = length of slower vehicle (ft),

V = speed of faster vehicle (mph),

Vi = speed difference between vehicles (mph),

150 = additional distance between the two vehicles before and after the passing maneuver (ft);

d(3) = distance between passing vehicle at the end of the passing maneuver and an opposing vehicle (ft);

d(4) = distance traversed by an opposing vehicle (ft).

Tables 2a and 2b show observed values for some of the above elements (Ref 3).

(B) While an increase in vehicle weight and width will have no effect on the above elements, an increase in vehicle length will have a pronounced effect on d(2) and d(4) .

This was confirmed by tests in Utah and Alberta, Canada (Refs 15 and 16). For scenarios A and B the maximum vehicle length remains 65 feet while for scenarios C and D it is increased to 105 feet.

AASHTO and SDHPT design values (Refs 3 and 20) are based on requirements for passenger cars passing passenger cars. Since it is common practice for cars to overtake trucks, additional length will be needed or more abortive passing maneuvers will result when the truck length is increased. The increase in abortive movements may have a detrimental effect on safety.

The following assumptions were made when calculating the extra passing sight distances required because of increased truck length:

(1) Car length is equal to 19 feet (Ref 3).

(2) Truck length is equal to 65 feet for scenarios A and B.

TABLE 2a. ELEMENTS OF SAFE PASSING SIGHT DISTANCE - 2-LANE HIGHWAYS

Speed group, mph	30-40	40-50	50-60	60-70
Average passing speed, mph	34.9	43.8	52.6	62.0
Initial maneuver:				
a = average acceleration mphps*	1.40	1.43	1.47	1.50
t_1 = time, seconds*	3.6	4.0	4.3	4.5
d_1 = distance traveled, feet	145	215	290	370
Occupation of left lane:				
t_2 = time, seconds*	9.3	10.0	10.7	11.3
d_2 = distance traveled, feet	475	640	825	1030
Clearance length:				
d_3 = distance traveled, feet*	100	180	250	300
Opposing vehicle:				
d_4 = distance traveled, feet	315	425	550	680
Total distance, $d_1+d_2+d_3+d_4$, feet	1035	1460	1915	2380

* For consistent speed relation, observed values adjusted slightly.

(Ref 3)

TABLE 2b. ELEMENTS OF SAFE PASSING SIGHT DISTANCE - 2-LANE HIGHWAYS

Design speed, mph	Assumed speeds	
	Passed vehicle, mph	Passing vehicle, mph
30	26	36
40	34	44
50	41	51
60	47	57
65	50	60
70	54	64
75*	56	66
80*	59	69

* Design speeds of 75 and 80 mph are applicable only to highways with full control of access or where such control is planned in the future.

(Ref 3)

(3) Truck length is equal to 105 feet for scenarios C and D.

(4) Speed difference between the two vehicles is 10 mph (Ref 12).

(5) Values for t and a are assumed according to observed AASHTO values (Ref 3).

(6) Overtaken vehicles travel at a uniform speed throughout the maneuvers.

(7) Passing vehicle slows down and trails the overtaken vehicle upon entering the passing zone.

(8) Values for d(3) are in the suggested range of 100 feet to 300 feet (Ref 3).

(9) d(4) = .666*d(2) .

Values obtained were tabulated and the comparative results are shown in Tables 3 and 4. From these it can be seen that passing sight distance will increase considerably due to an increase in vehicle length. But pavement markings that prohibit passing maneuvers are warranted according to the "Manual on Uniform Traffic Control Devices" (Ref 1) when passing sight distance measured from a height 3.75 feet above the pavement to an object 3.75 feet is less than:

30 mph	:	500 feet
40 mph	:	600 feet
50 mph	:	800 feet
60 mph	:	1,000 feet
70 mph	:	1,200 feet

(C) It must be borne in mind that the existing AASHTO procedure is based upon the assumption that a passenger car overtakes a passenger car. If the case where a car overtakes a truck is considered in any one of scenarios A, B, C, or D, a considerable revision of the AASHTO standards for passing sight distance can be expected. If the procedure for computing passing sight is not altered, more abortive maneuvers will result. An increase in abortive passing maneuvers may have serious safety implications, so the procedure to calculate passing sight distance and the procedure that warrants restricted pavement markings need further attention. But this falls outside the scope of this subprogram of Project 241.

TABLE 3. MINIMUM PASSING SIGHT DISTANCE FOR TWO-LANE HIGHWAYS WITH A MAXIMUM VEHICLE LENGTH OF 65 FEET (SCENARIOS A, B)

Design speed, mph	Assumed speeds.mph		avg. a, mphps	t, sec	Calc. PSD, ft	AASHTO PSD, ft	Extra req., ft
	passed vehicle	passing vehicle					
30	26	36	1.40	3.6	1700	1100	600
40	34	44	1.41	3.8	2100	1500	600
50	41	51	1.45	4.1	2500	1800	700
60	47	57	1.48	4.4	2800	2100	700
65	50	60	1.50	4.5	3000	2300	700
70	54	64	1.50	4.5	3200	2500	700
75	56	66	1.50	4.5	3300	2600	700
80	59	69	1.50	4.5	3400	2700	700

TABLE 4. MINIMUM PASSING SIGHT DISTANCE FOR TWO-LANE HIGHWAYS WITH A MAXIMUM VEHICLE LENGTH OF 105 FEET (SCENARIOS C, D)

Design Speed, mph	Assumed Speeds, mph		avg. a, mphps	t, sec	Calc. PSD, ft	AASHTO PSD, ft	Extra Req. Ft
	Passed Vehicle	Passing Vehicle					
30	26	36	1.40	3.6	1900	1100	800
40	34	44	1.41	3.8	2400	1500	900
50	41	51	1.45	4.1	2800	1800	1000
60	47	57	1.48	4.4	3200	2100	1100
65	50	60	1.50	4.5	3400	2300	1100
70	54	64	1.50	4.5	3600	2500	1100
75	56	66	1.50	4.5	3700	2600	1100
80	59	69	1.50	4.5	3900	2700	1200

2.3. PAVEMENT WIDENING ON CURVES

(A) AASHTO (Ref 3) states that "pavements on curves are sometimes widened to make operating conditions on curves comparable to those on tangents." The justifications are based on truck operating characteristics:

(1) The rear wheels track inside of the front wheels (this tracking distance is called the "offtracking distance").

(2) It is difficult to steer the vehicle so that it holds the center of the lane.

The following formula gives maximum offtracking values that were experimentally found to be close to the real measured offtracking (Refs 15, 25, and 26):

MOT = R(1) -SQRT(R(1)*R(1) -SUM(L*L))

where

MOT = maximum offtracking (feet),

R(1) = turning radius of outside front wheel (feet),

SUM(L*L) = L(1)*L(1) + L(2)*L(2) + etc.

and where

L(1) = wheelbase of tractor (feet),

L(2) = wheelbase of first trailer (feet),

L(3) = distance between rear axle and articulation point (feet),

L(4) = distance between articulation point and front axle of next trailer (feet), and

L(5) = wheelbase of next trailer (feet).

Extra width to compensate for the difficulty of driving on curves can be computed from

$$Z = V/SQRT(R) \quad \text{(Ref 3)}$$

where

Z = extra width (feet),

V = design speed (mph), and

R = radius on center line (feet).

The width of the overhang can be computed as follows:

$$Fa = SQRT(R*R + A(2*L + A)) - R \quad \text{(Ref 3)}$$

where

Fa = width of overhang (feet),

R = radius of centerline (feet),

A = overhang (feet), and

L = wheelbase of unit (feet).

The width of a two-lane pavement on a curve can then be computed from

$$W1 = 2*(U + C) + Fa + Z$$

where

U = vehicle track width (feet) and

C = lateral clearance per vehicle (2, 2.5, or 3 feet for 20, 22, or 24-foot pavement widths).

(B) From the above formulas it can be seen that vehicle configuration and length will have an effect on pavement widening while vehicle weight and height are not considered. The maximum vehicle width proposed for scenarios C and D is 8.5 feet and this is the same as the maximum for the AASHTO design vehicles but 6 inches wider than the Texas maximum. When using the formulas mentioned in (A) above, new widths for pavement widening on curves were calculated for the 3-S2-4 and 2-S1-2-2 vehicle types.

The results obtained from these calculations are shown in Table 5. In Table 6 the width of pavement to be added to existing pavements designed according to current AASHTO standards is calculated. It was assumed when calculating Table 6 that when the original pavement design was done values of less than 2 feet were disregarded (Ref 3). This holds true when designing for the new vehicle configuration.

In Table 7 the AASHTO values (Ref 3) are shown, while vehicle configurations are shown in Table 8 (Ref 25).

(C) While both vehicle types, namely the 3-S2-4 and 2-S2-2-2, are proposed in only scenarios C and D, no change is expected for scenario B. The increased values shown in Table 5 will be used for new roads and the values shown in Table 6 will be used for the reconstruction of existing inadequate pavements when either scenario C or D is implemented.

2.4. CRITICAL LENGTHS OF GRADES

(A) According to AASHTO (Ref 3), climbing lanes should be provided on the upgrade side of a two-lane rural highway when:

(1) The length of upgrade causes a speed reduction of 15 mph or more.

(2) The added cost is justified by the volume of traffic and percentage of trucks.

(3) It is further desirable to end the climbing lane at a point beyond the crest where a truck could obtain a speed of 30 mph. But this is sometimes impractical due to the length, and the lane is ended when sufficient sight distance is obtained. The SDHPT differs from the above in that it requires that climbing lanes should be provided when the length of upgrade causes a speed reduction of 10 mph or more (Ref 20).

(B) It is worth noting that a greater speed reduction is associated with a higher accident involvement rate (Refs 7 and 23). The ratios derived are shown in Table 9.

TABLE 5. CALCULATED VALUES FOR PAVEMENT WIDENING ON 2-LANE PAVEMENTS

Vehicle Type	Degree of Curve	Widening, in Feet, for 2-Lane Pavements on Curves for Width of Pavement on Tangent of 24 Feet						22 Feet					20 Feet			
		For Design Speed in mph of														
		30	40	50	60	70	80	30	40	50	60	70	30	40	50	60
3-S2-4	1	0.0	0.0	0.5	0.5	0.5	1.0	1.0	1.0	1.5	1.5	1.5	2.0	2.0	2.5	2.5
2-S1-2-2		0.0	0.0	0.0	0.5	0.5	1.0	1.0	1.0	1.0	1.5	1.5	2.0	2.0	2.0	2.5
3-S2-4	2	0.5	1.0	1.5	1.5	2.0	2.0	1.5	2.0	2.5	2.5	3.0	2.5	3.0	3.5	3.5
2-S1-2-2		0.5	0.5	1.0	1.0	1.5	1.5	1.5	1.5	2.0	2.0	2.5	2.5	2.5	3.0	3.0
3-S2-4	3	1.5	1.5	2.0	2.5	2.5	3.0	2.5	2.5	3.0	3.5	3.5	3.5	3.5	4.0	4.5
2-S1-2-2		1.0	1.0	1.5	2.0	2.0	2.5	2.0	2.0	2.5	3.0	3.0	3.0	3.0	3.5	4.0
3-S2-4	4	2.0	2.5	2.5	3.0	3.5		3.0	3.5	3.5	4.0	4.5	4.0	4.5	4.5	5.0
2-S1-2-2		1.0	1.5	2.0	2.5	3.0		2.0	2.5	3.0	3.5	4.0	3.0	3.5	4.0	4.5
3-S2-4	5	2.5	3.0	3.5	4.0			3.5	4.0	4.5	5.0		4.5	5.0	5.5	6.0
2-S1-2-2		1.5	2.0	2.5	3.0			2.5	3.0	3.5	4.0		3.5	4.0	4.5	5.0
3-S2-4	6	3.0	3.5	4.0	4.5			4.0	4.5	5.0	5.5		5.0	5.5	6.0	6.5
2-S1-2-2		2.0	2.5	3.0	3.5			3.0	3.5	4.0	4.5		4.0	4.5	5.0	5.5
3-S2-4	7	3.5	4.0	4.5				4.5	5.0	5.5			5.5	6.0	6.5	
2-S1-2-2		2.5	3.0	3.5				3.5	4.0	4.5			4.5	5.0	5.5	
3-S2-4	8	4.0	5.0	5.5				5.0	6.0	6.5			6.0	7.0	7.5	
2-S1-2-2		2.5	3.5	4.0				3.5	4.5	5.0			4.5	5.5	6.0	
3-S2-4	9	5.0	5.5	6.0				6.0	6.5	7.0			7.0	7.5	8.0	
2-S1-2-2		3.0	3.5	4.5				4.0	4.5	5.5			5.0	5.5	6.5	
3-S2-4	10-11	6.0	6.5					7.0	7.5				8.0	8.5		
2-S1-2-2		4.0	4.5					5.0	5.5				6.0	6.5		
3-S2-4	12-14.5	7.5	8.5					8.5	9.5				9.5	10.5		
2-S1-2-2		5.0	6.0					6.0	7.0				7.0	8.0		
3-S2-4	15-18	9.5						10.5					11.5			
2-S1-2-2		6.0						7.0					8.0			
3-S2-4	19-21	11.0						12.0					13.0			
2-S1-2-2		7.0						8.0					9.0			
3-S2-4	22-25	13.0						14.0					15.0			
2-S1-2-2		8.5						9.5					10.5			
3-S2-4	26-26.5	14.0						15.0					16.0			
2-S1-2-2		9.0						10.0					11.0			

TABLE 6. DIFFERENCE BETWEEN PRACTICAL AASHTO VALUES AND NEW CALCULATED VALUES TAKING INTO ACCOUNT THAT VALUES OF LESS THAN 2.0 FEET ARE DISCARDED

Vehicle Type	Degree of Curve	Additional Widening, in Feet, for 2-Lane Pavements Should 3-S2-4 or 2-S1-2-2 Trucks be Introduced — 24 Feet						22 Feet (For Design Speed in mph of)					20 Feet			
		30	40	50	60	70	80	30	40	50	60	70	30	40	50	60
3-S2-4	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2-S1-2-2		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3-S2-4	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2-S1-2-2		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3-S2-4	3	0.0	0.0	0.0	2.0	0.0	2.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	2.0
2-S1-2-2		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3-S2-4	4	2.0	2.0	2.0	2.0	2.5		2.0	2.0	2.0	2.0	2.5	2.0	2.0	2.0	2.0
2-S1-2-2		0.0	0.0	0.0	0.0	2.0		0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0
3-S2-4	5	2.0	2.5	2.5	3.0			2.0	2.5	2.5	3.0		2.0	2.5	2.5	3.0
2-S1-2-2		0.0	0.0	0.0	2.0			0.0	0.0	0.0	2.0		0.0	0.0	0.0	2.0
3-S2-4	6	2.5	2.5	3.0	3.0			2.5	2.5	3.0	3.0		2.5	2.5	3.0	3.0
2-S1-2-2		0.0	0.0	2.0	2.0			0.0	0.0	2.0	2.0		0.0	0.0	2.0	2.0
3-S2-4	7	3.0	3.0	3.0				3.0	3.0	3.0			3.0	3.0	3.0	
2-S1-2-2		0.0	2.0	2.0				0.0	2.0	2.0			0.0	2.0	2.0	
3-S2-4	8	3.0	4.0	4.0				3.0	4.0	4.0			3.0	4.0	4.0	
2-S1-2-2		0.0	2.5	2.5				0.0	2.5	2.5			0.0	2.5	2.5	
3-S2-4	9	4.0	4.0	4.0				4.0	4.0	4.0			4.0	4.0	4.0	
2-S1-2-2		2.0	2.0	2.5				2.0	2.0	2.5			2.0	2.0	2.5	
3-S2-4	10-11	5.0	5.0					5.0	5.0				5.0	5.0		
2-S1-2-2		3.0	3.0					3.0	3.0				3.0	3.0		
3-S2-4	12-14.5	6.0	6.5					6.0	6.5				6.0	6.5		
2-S1-2-2		3.5	4.0					3.5	4.0				3.5	4.0		
3-S2-4	15-18	7.5						7.5					7.5			
2-S1-2-2		4.0						4.0					4.0			
3-S2-4	19-21	8.5						8.5					8.5			
2-S1-2-2		4.5						4.5					4.5			
3-S2-4	22-25	10.0						10.0					10.0			
2-S1-2-2		5.5						5.5					5.5			
3-S2-4	26-26.5	10.5						10.5					10.5			
2-S1-2-2		5.5						5.5					5.5			

TABLE 7. CALCULATED AND DESIGN VALUES FOR PAVEMENT WIDENING ON OPEN HIGHWAY CURVES (2-LANE PAVEMENTS, ONE-WAY OR TWO-WAY)

Degree of curve	Widening, in feet, for 2-lane pavements on curves for width of pavement on tangent of: 24 feet						22 feet					20 feet			
	Design speed, mph						Design speed, mph					Design speed, mph			
	30	40	50	60	70	80	30	40	50	60	70	30	40	50	60
1	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.5	0.5	1.0	1.0	1.5	1.5	1.5	2.0
2	0.0	0.0	0.0	0.5	0.5	0.5	1.0	1.0	1.0	1.5	1.5	2.0	2.0	2.0	2.5
3	0.0	0.0	0.5	0.5	1.0	1.0	1.0	1.0	1.5	1.5	2.0	2.0	2.0	2.5	2.5
4	0.0	0.5	0.5	1.0	1.0		1.0	1.5	1.5	2.0	2.0	2.0	2.5	2.5	3.0
5	0.5	0.5	1.0	1.0			1.5	1.5	2.0	2.0		2.5	2.5	3.0	3.0
6	0.5	1.0	1.0	1.5			1.5	2.0	2.0	2.5		2.5	3.0	3.0	3.5
7	0.5	1.0	1.5				1.5	2.0	2.5			2.5	3.0	3.5	
8	1.0	1.0	1.5				2.0	2.0	2.5			3.0	3.0	3.5	
9	1.0	1.5	2.0				2.0	2.5	3.0			3.0	3.5	4.0	
10-11	1.0	1.5					2.0	2.5				3.0	3.5		
12-14.5	1.5	2.0					2.5	3.0				3.5	4.0		
15-18	2.0						3.0					4.0			
19-21	2.5						3.5					4.5			
22-25	3.0						4.0					5.0			
26-26.5	3.5						4.5					5.5			

NOTE: Values less than 2.0 may be disregarded.
3-lane pavements: multiply above values by 1.5.
4-lane pavements: multiply above values by 2.
Where semitrailers are significant, increase tabular values of widening by 0.5 for curves of 10 to 16 degrees, and by 1.0 for curves 17 degrees and sharper.

(Ref 3)

TABLE 8. MAXIMUM OFFTRACKING (WESTERN HIGHWAY INSTITUTE)

Vehicle No.	Vehicle Type	Maximum Offtracking (ft), scenario C and D vehicle configurations	Maximum Offtracking (ft), Western Highway Institute vehicle configurations
1			3.4
2			2.3
3			4.0
4			4.0
5			4.2
6			5.4
7			3.4
8			2.9
9			3.5
10			3.0
11		4.5	4.5
12		8.2	8.1

Obtained with scenario C and D vehicle configurations

Obtained with Western Highway Institute vehicle configurations

(Ref 25)

TABLE 9. ACCIDENT RATE VERSUS SPEED REDUCTION

Reduction	Accident Involvement Rate	Rate Ratio Related to 0 Speed Reduction
0	247	1.00
5	481	1.95
10	913	3.70
15	2,193	8.90
20	3,825	15.90

(Refs 7 and 23)

The size, power, gradability, and entrance speed of the truck contribute towards the performance of trucks on a grade. Their combined effect will lead to the maximum allowable speed reduction of 10 or 15 mph (Refs 3 and 20).

AASHTO (Ref 3) uses the nationally representative truck with a GVW (pounds) to net hp ratio of 400:1 to evaluate the performance (acceleration and deceleration) of trucks on a grade.

The average weight to power is declining (Refs 3 and 24) and the Western Highway Institute states that "vehicles with a ratio of 325:1 will have a performance that is acceptable to most operators, while a vehicle with a 454:1 ratio will have a performance that would probably be unacceptable" (Ref 24).

It seems reasonable to assume that vehicles with a GVW of up to 126,000 pounds will have a ratio lower than 400:1 (Ref 24). The present availability of engines big enough to provide the 400:1 ratio underlines this assumption. Table 10 provides the range of diesel engines currently available (Ref 6).

Today's high torque rise engines and transmissions are superior to those of the old national representative truck, and therefore the gradability and entrance speed of today's truck is higher than that of the national representative truck (Refs 17, 22, and 24). Increased entrance speeds and transmissions of trucks essentially offset the detrimental effects of increased weight, with a net result of gradability performance regressing to the approximate level of AASHTO's (Ref 3) representative 1950's truck.

TABLE 10. DIESEL ENGINE HP RANGE

70-205			210-290			300-600		
			Cat	210	3208	Cat	300	3406
			DDA	210	6-71	DDA	304	8V-71
Perkins	70	4.165	I-H	210	DT-466	Cat	305	3406
Perkins	98	6.247	Mack	210	ETZ 477	DDA	305	8V-71TTA
Deutz	100	F5L912	Perkins	215	V8.640	DDA	305	8V-71TTAC
Mercedes	120	OM352	Cummins	225	VT-225	Mack	315	ETAZ 673A
Perkins	124	6.354	Cummins	230	Formula 230	Cummins	320	VT-903
Mercedes	145	OM352A	Cummins	230	NTC-230	Cat	325	3406
I-H	150	D-150	DDA	230	6-71	DDA	335	6V-92TAC
Perkins	155	T6.354	DDA	230	6-71TT	Cat	340	3406
Cat	160	3208	Volvo	230	TD70F	Cat	350	3406
Deutz	160	BF6L913	Mack	237	ENDT 675	Cummins	350	Formula 350
Magirus	160	Fiat 8360.05	Cat	245	3306	Cummins	350	NTC-350
DDA	170	4-53T	Cat	250	3306	Cummins	350	VT-350
I-H	170	D-170	Cummins	250	Formula 250	DDA	350	8V-71TAC
Volvo	170	TD-60	Cummins	250	NTC-250	DDA	365	8V-92TTA
Cat	175	3208	Perkins	250	TV8.640	DDA	370	8V-92TTAC
I-H	180	DT-466	Mack	260	ET 673	DDA	370	8V-71TA
Mercedes	180	OM355/5	Cat	270	3306	Cat	375	3406
Perkins	180	V8.540	DDA	270	6V-92TTA	Cat	400	3408
Cat	185	3208	DDA	270	6V-92TTAC	Cummins	400	NTC-400
I-H	190	D-190	DDA	275	6-71T	DDA	430	8V92TAC
I-H	190	DT-466	Cat	280	3406	DDA	435	8V92TA
Cat	200	3208	Mack	285	ENDT 676	Cat	450	3408
DDA	200	6V-71	Cat	290	3406	Cummins	450	KT-450
Mack	200	ETG73E	Cummins	290	Formula 290	Cummins	525	Formula 525
Magrius	200	Fiat 8220.02	Cummins	290	NTC-290	Cummins	525	KTA-525
Volvo	205	TD70E	Cummins	290	Formula 903	Cummins	600	KTA-600

(Ref 6)

Trucks further reduce traffic volume because of the difference between the average running speed of cars and trucks and because they occupy more space. A. Werner and John F. Marshall suggest that speed difference is the only criterion for calculating passenger car equivalency for trucks on grades, while the space they occupy influences only the equivalent factor for trucks operating on flat surfaces (Ref 23). Increased length will therefore have no influence on climbing lane criteria.

Because of increased passing sight distance requirements, the practical length of climbing lanes may be influenced by the longer truck lengths of scenarios C and D. The passing sight distance requirements are listed in Table 11.

TABLE 11. PASSING SIGHT DISTANCE (FEET)

Design Speed, mph	Scenarios A , B Truck Length = 65	Scenarios C , D Truck Length = 105
30	1700 (1100)	1900
40	2100 (1500)	2400
50	2500 (1800)	2800
60	2800 (2100)	3200
65	3000 (2300)	3400
70	3200 (2500)	3600
75	3300 (2600)	3700
80	3400 (2700)	3900

Values in parentheses are the AASHTO (Ref 3) minimum values while the other values were calculated for truck lengths of 65 feet and 105 feet. Should scenarios C or D be implemented, allowance for the increase in passing sight distance due to the increased 40 feet truck length should be made. This will vary from 200 feet to 500 feet depending on the design speed of the road.

(C) Due to the changed performance of today's trucks in comparison to that of the old national representative truck, speed reduction curves based on more recent data can be expected. In Fig 5 (Ref 3) the current AASHTO deceleration curves based on observations made prior to 1955 are shown. Figure 6 (Ref 20) shows deceleration curves based on observations made during 1973, while those shown in Fig 7 (Ref 18) are based on observations made during 1977 to 1979. This upward trend will be more representative of what to use in the future. The only other expected change may be due to an increase in passing sight distance requirements and the climbing lanes may be ended when the new passing sight distances are met for scenarios C or D.

2.5. REST AREAS

(A) Rest areas are to be provided on highways as a safety measure with provision for emergency stopping and resting by motorists for short periods (Ref 4). The spacing should be such that in combination with other stopping opportunity (e.g., service facilities) there will preferably be a stopping facility for every half hour of driving (Refs 4 and 20). When a number of truck-trailer combinations are expected to use the area, angle parking should be considered. The WB50 should be used according to current AASHTO policy as the design vehicle (Ref 4). A typical SDHPT layout is shown in Fig 8 (Ref 20).

(B) According to AASHTO policy (Ref 4), the parking areas are to be designed with the WB50 as the design vehicle. Should scenarios B, C, or D be introduced, vehicles longer than the WB50 should be considered. By using the same formulas as in "Pavement Widening on Curves," Table 12 (the maximum expected offtracking) was computed. Table 13 shows the extra pavement width needed for two-lane operation should the design truck be increased from the WB50 to the 3-S2-4 or the 2-S1-2-2.

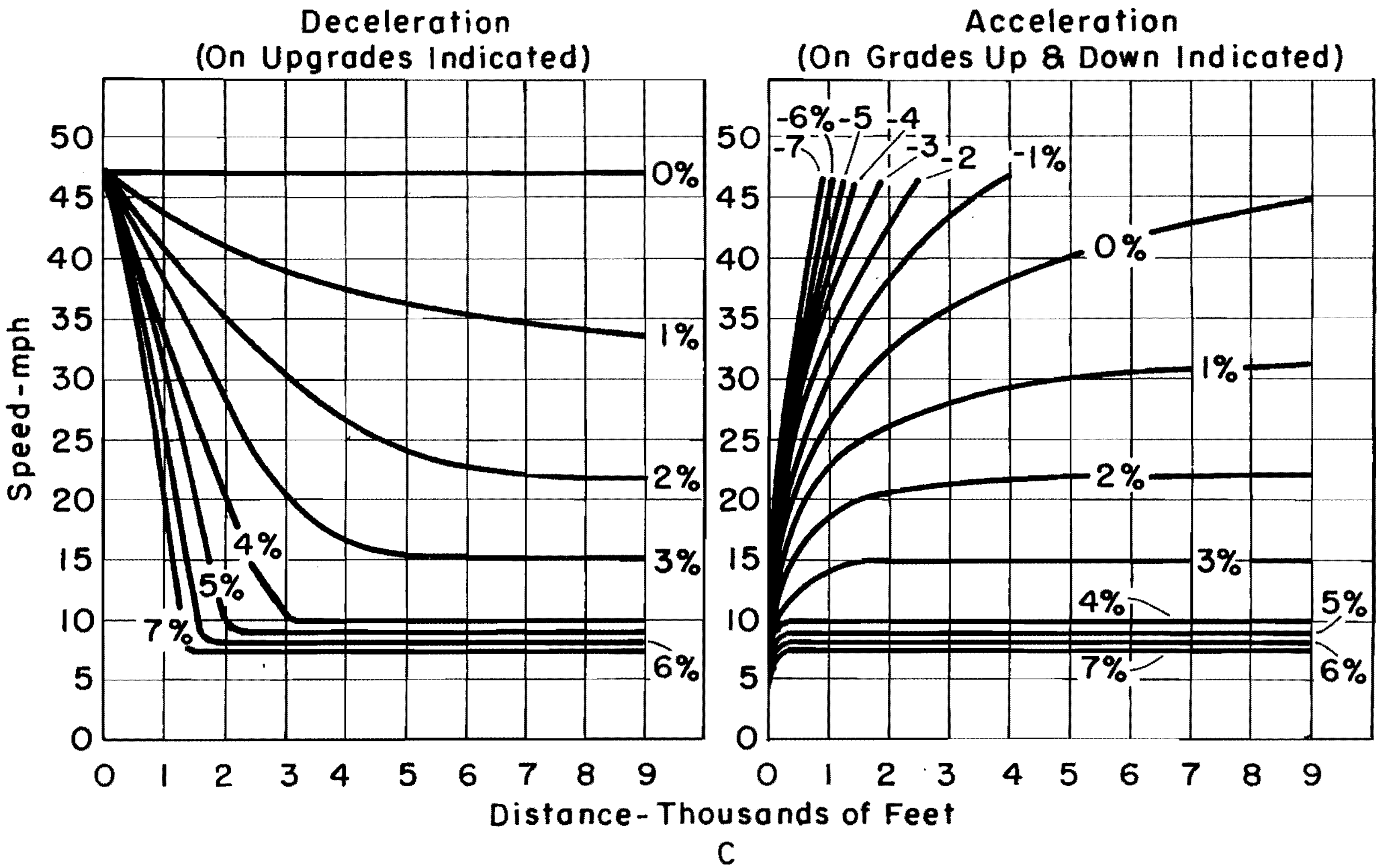


Fig 5. AASHTO deceleration curves (Ref 3).

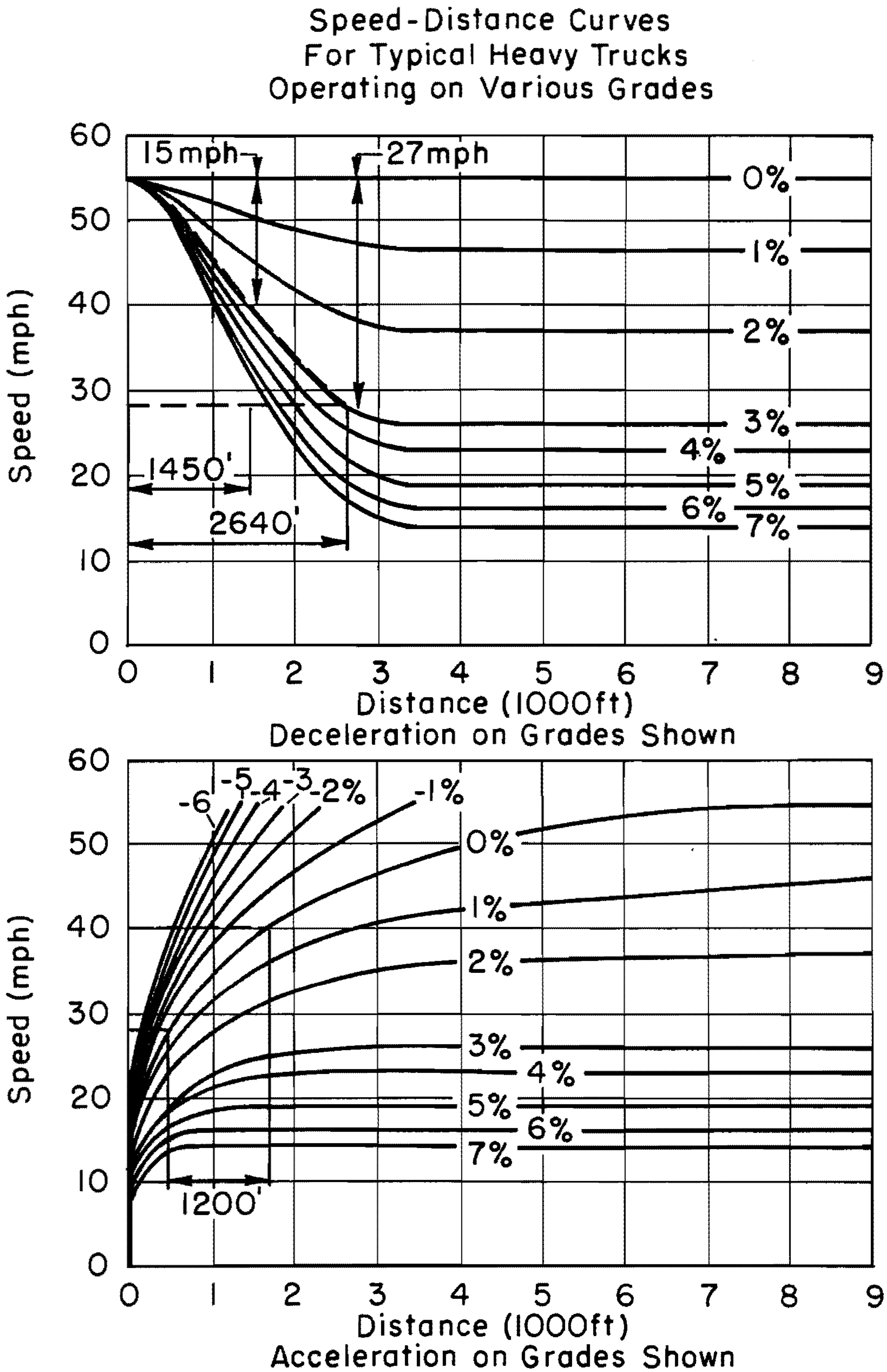


Fig 6. Texas deceleration curves (Ref 20).

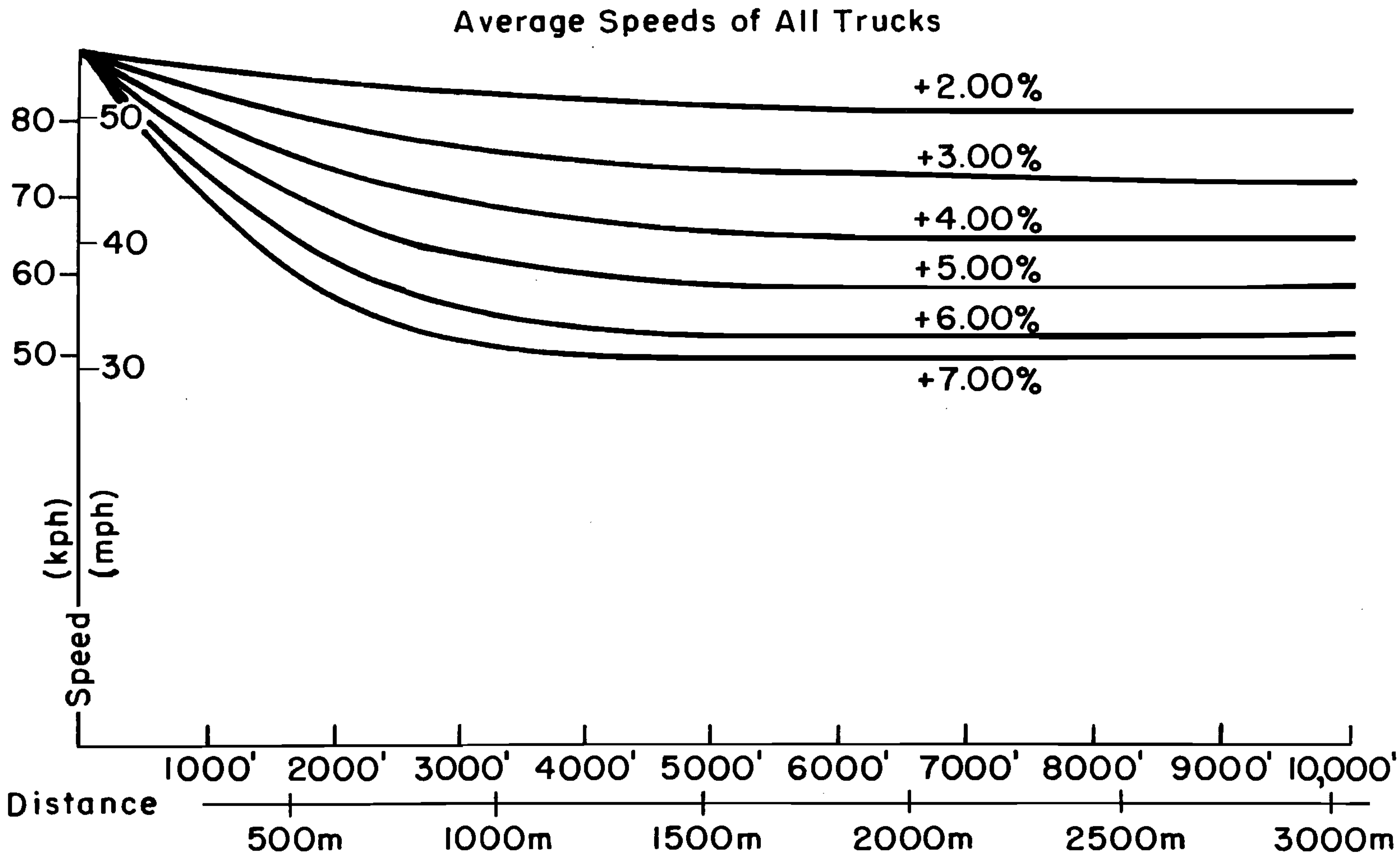


Fig 7. New deceleration curves from tests in California (Ref 18).

Typical Designs for Safety Rest Areas

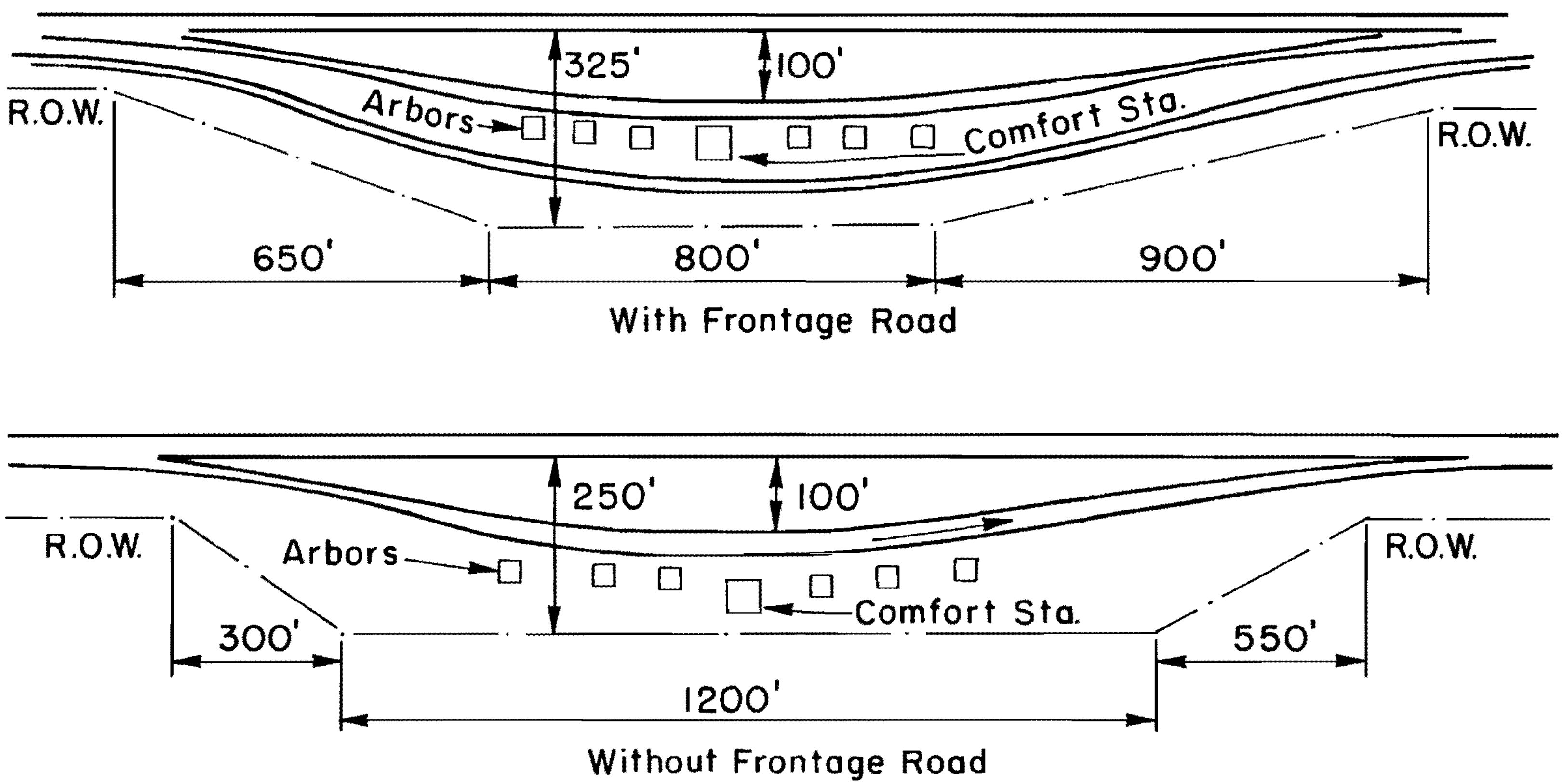


Fig 8. Safety rest area layout (Ref 20).

TABLE 12. MAXIMUM OFFTRACKING (FEET)

R (ft)	WB50	3-S2-4	2-S1-2-2
200	3.5	6.5	3.5
180	4.0	7.0	4.0
160	4.5	8.0	4.5
140	5.0	9.0	5.5
120	6.0	11.0	6.5
100	7.0	13.0	7.5
80	9.0	17.0	9.5
60	12.5	26.5	13.0

TABLE 13. EXTRA PAVEMENT WIDTH WHEN DESIGN TRUCK IS 3-S2-4 OR 2-S1-2-2

R (ft)	3-S2-4 10 mph	3-S2-4 20 mph	2-S1-2-2 10 mph	2-S1-2-2 20 mph
200	6.0	6.0	0	0
180	6.0	6.0	0	0
160	7.0	7.0	0	0
140	8.0	8.0	1.0	1.0
120	10.0	10.0	1.0	1.0
100	12.0	---	1.0	---
80	16.0	---	1.0	---
60	28.0	---	1.0	---

Note: The above are extra over that for WB50.

When designing facilities to accommodate scenarios C or D it must be ensured that the combined lane widths and radii are big enough to accommodate the expected maximum offtracking.

(C) While the vehicles proposed under scenarios C and D have different characteristics (i.e., offtracking and length) from the WB50 vehicle, the following changes are expected should scenarios C or D be implemented:

(1) Larger parking bays where these vehicles are expected.

(2) Wider lanes where offtracking necessitates it.

(3) Additional safety rest areas if existing non-departmental facilities are too small to accommodate the larger vehicles.

CHAPTER 3. CROSS SECTION ELEMENTS

3.1. LANE WIDTH

(A) AASHTO states (Ref 3) that on rural two-way highways hazardous conditions exist on pavements less than 22 feet wide when even a moderate volume of mixed traffic is present due to inadequate body clearance.

Body and edge clearance for meeting or passing vehicles were identified as critical factors in judging the adequacy of pavement width (Ref 26). In the experiments conducted in the earlier days of highway construction, two important observations were made (Ref 19).

(1) Only on 24 feet pavements were drivers apparently satisfied with both edge and body clearance; and

(2) Drivers of passenger cars prefer a body clearance of about 5 feet when meeting other passenger cars. This cannot be obtained on pavements of a width less than 22 feet.

(B) From the above it is clear that only vehicle width will have an impact on lane width. The following AASHTO design vehicles all have a present width of 8.5 feet, namely the SU, WB40, WB50, WB60, and the BUS. While no change in vehicle width is proposed in scenarios B, C, or D from the existing AASHTO standards, it will differ from the allowable legal limit in Texas of 8.0 feet (Refs 3 and 26). Should the Legislature adopt a wider vehicle width, the following should be borne in mind.

Although a 10-foot lane width may be an acceptable minimum on arterials carrying a few commercial vehicles (Refs 3 and 19), it is difficult to control the number and movement of commercial vehicles. Although substantial lane flow is accommodated, driving on such lanes is accomplished only by undesirable tension and strain on the part of the drivers, especially at other than low speed (Ref 3).

The average body clearance of 2.6 and 3.5 feet for passenger cars meeting commercial vehicles on 18 and 20-foot pavements respectively, appeared to be inadequate for safety (Ref 19). Figures 9 and 10 show the body and edge clearances on 20-foot and 22-foot pavements (Ref 11).

A study was conducted by the Bureau of Public Roads in the 1960's on the "Perceptual and field relationship between vehicle width and lateral lane placement" (Ref 12). The study observed that small changes in vehicle width caused large changes in frequency and magnitude of lateral lane placement. Pavement markings did not significantly alter lateral placement of vehicles. The study also established relationships between speed and later separation, and speed and lane width. See Figures 11 and 12.

Based on relationships in Figs 11 and 12 and clearance data, minimum required speeds that will not cause disturbances to traffic flow can be obtained for 96-inch and 102-inch trucks. Table 14 gives the minimum speed of a 96-inch truck or a 102-inch truck that will have no influence on approaching vehicles as estimated from analysis of observed data in other studies (Ref 12).

TABLE 14. MINIMUM SPEEDS TO AVOID DISTURBANCES

Lane Width, feet	Truck Width, inches	Minimum Speed, mph
10	96	72
10	102	88
11	96	53
11	102	63
12	96	43
12	102	45
13	96	33
13	102	35

The relationships from the tables indicate that for a truck of 102-in. width to have no influence on traffic flow when travelling on two-lane highways 22 feet wide, it has to be driven at a speed above the 55 mph speed limit. If the 102-in. truck keeps within the 55 mph speed limit, it will

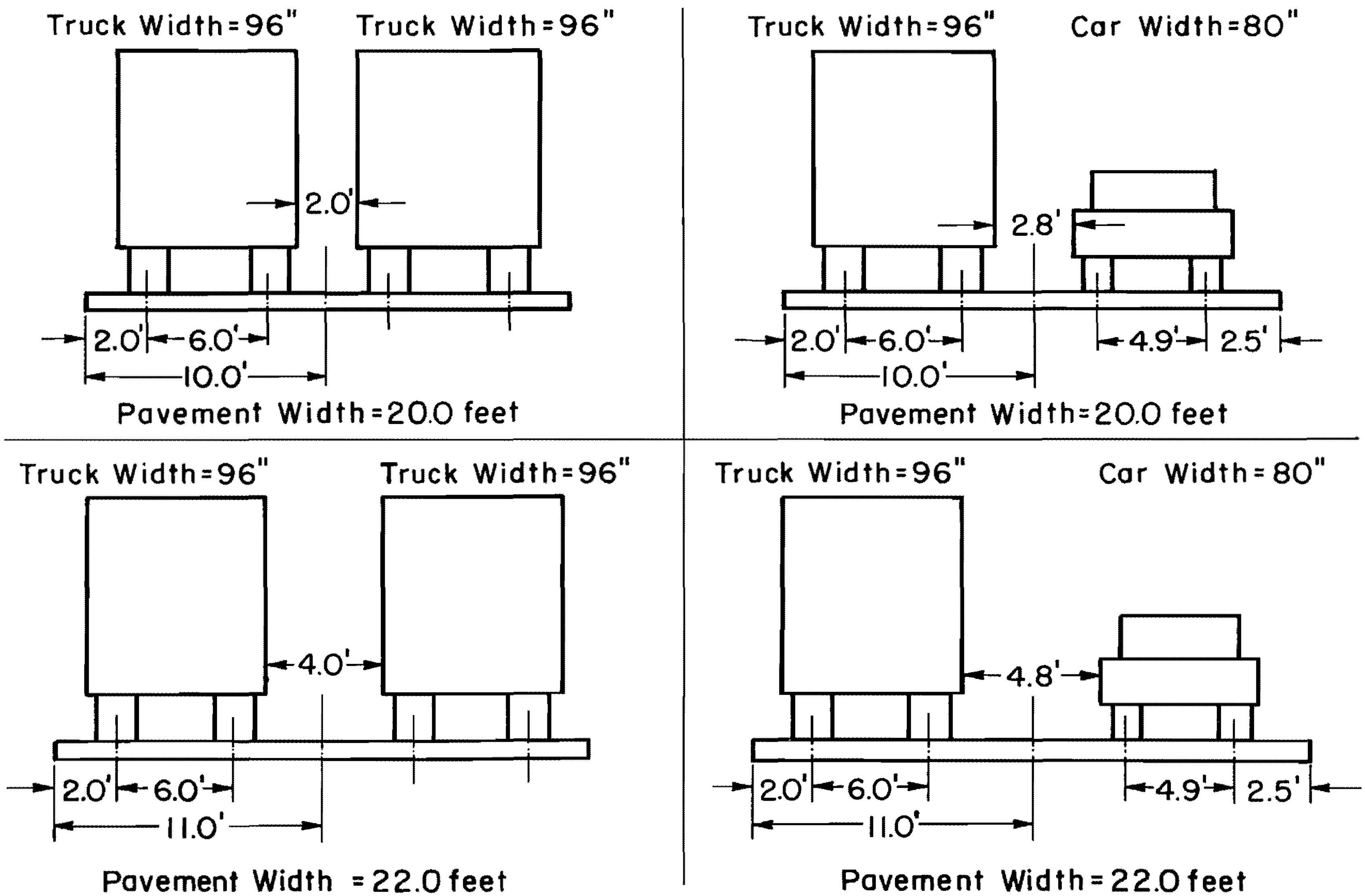


Fig 9. Lane placement (Ref 11).

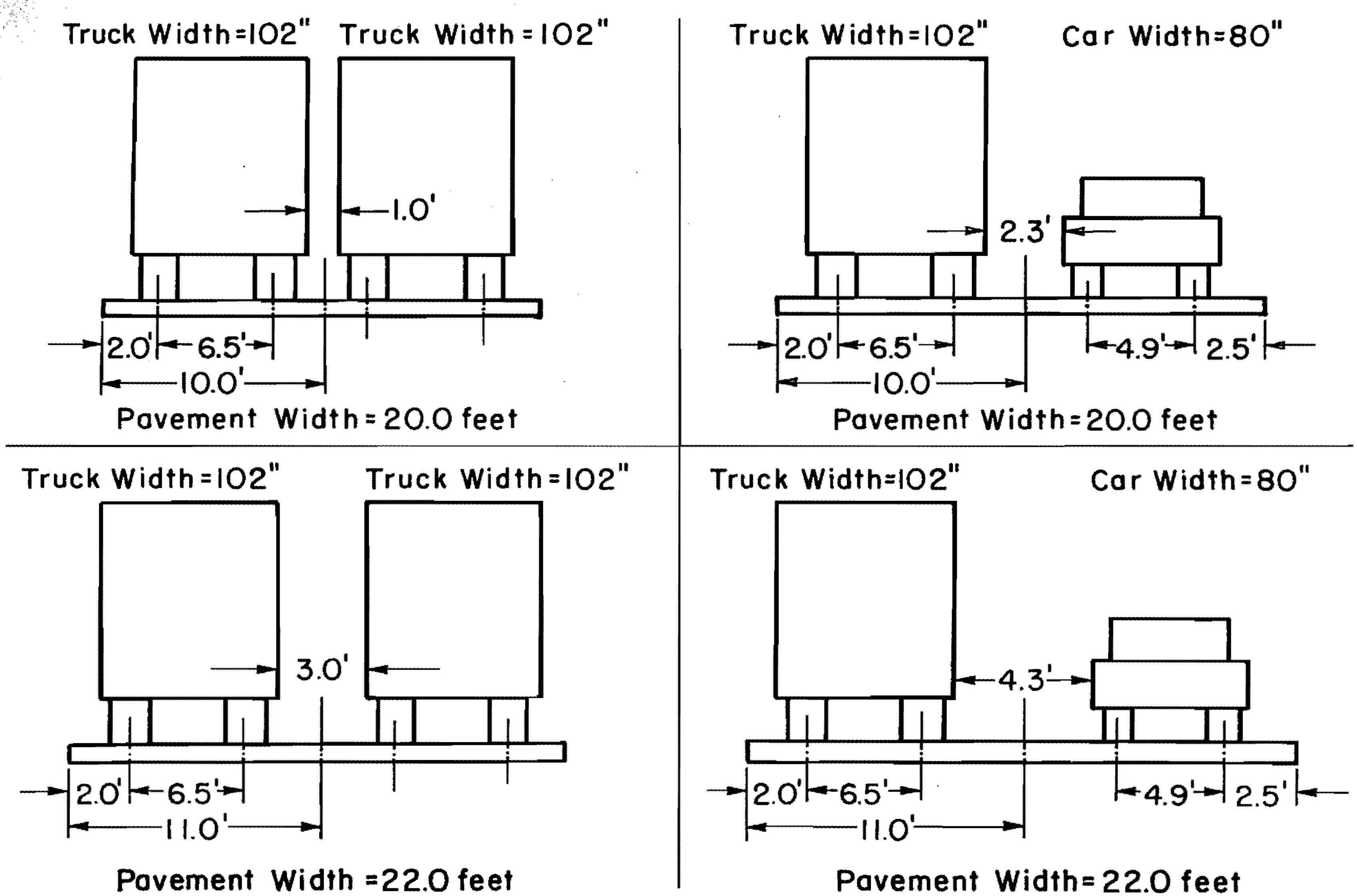


Fig 10. Lane placement (Ref 11).

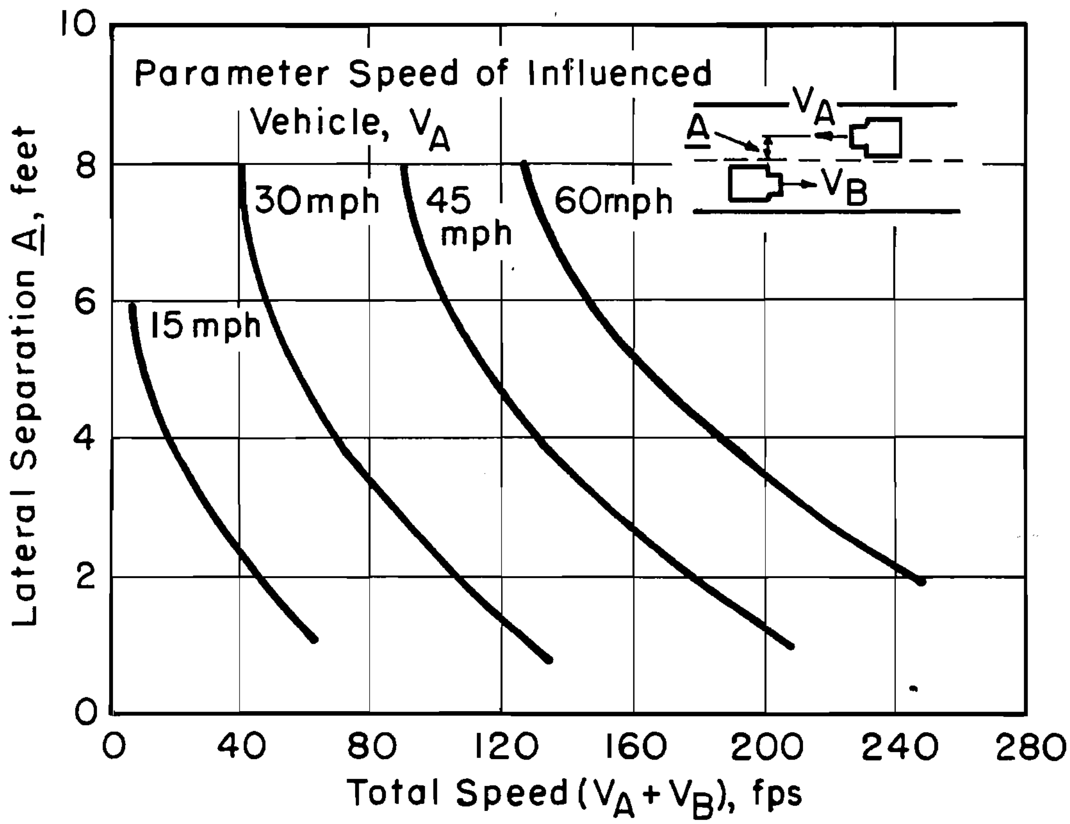


Fig 11. Lateral separation and speed functions that influence approaching vehicles (Ref 12).

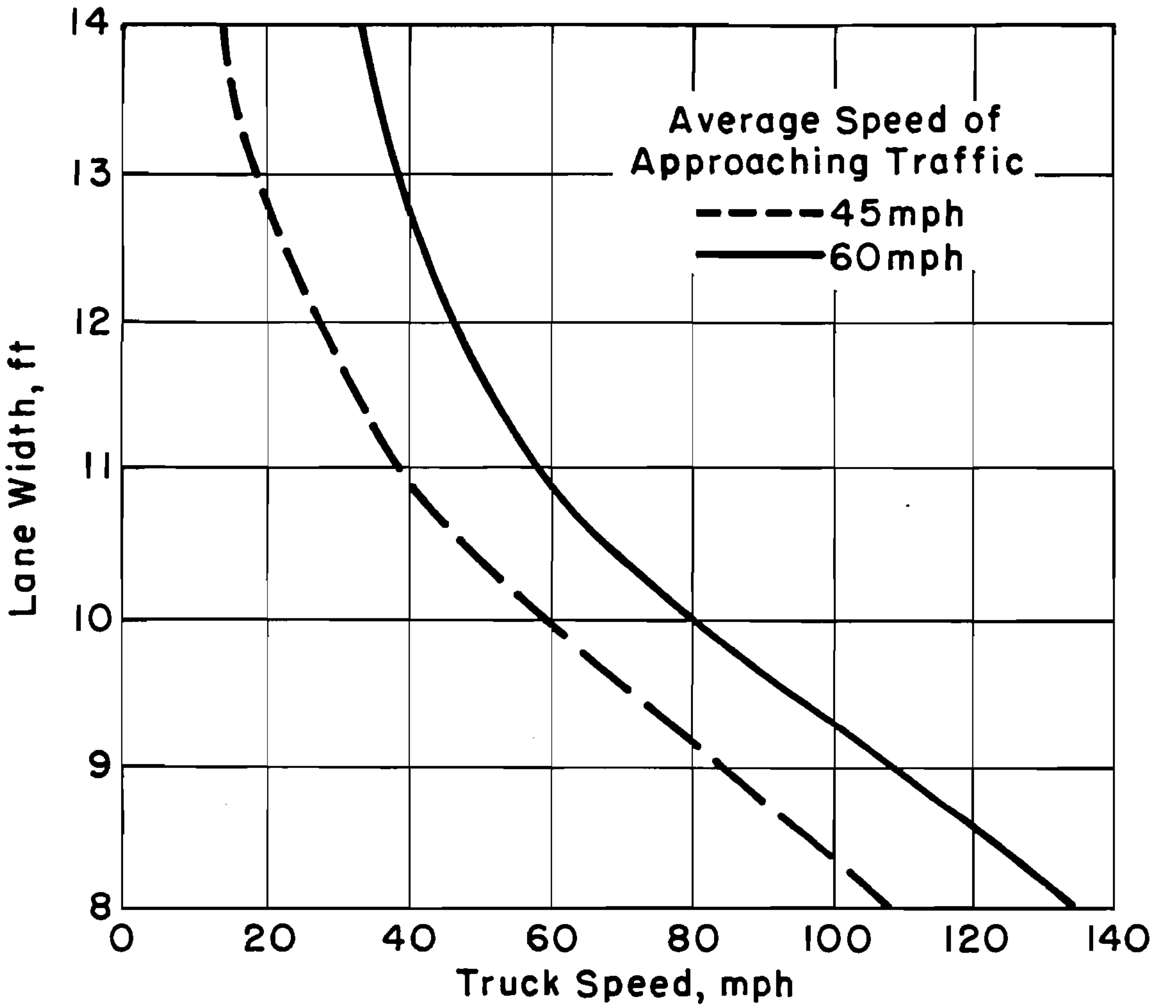


Fig 12. Minimum speed of 96-inch trucks that has no influence on approaching vehicles (Ref 12).

create disturbances in the flow of oncoming traffic. It will also create strain and tension on drivers. This is in direct conflict with the function of lane width which is to provide safety and comfort.

The question of minimum lane width for safe operation of 102-in.-wide trucks is a difficult one, especially for multilane highways. According to Hansen (Ref 8), there is no evidence to indicate that an increase in width of 6 inches would result in an increased number of accidents. It seems practical to allow for a gradual modification of lane width to 12 feet for the operation of 102-in.-wide trucks. AASHTO (Ref 3) did not specifically address this issue; however, the lane width that it recommends is from 11 to 13 feet. During an initial period, the operation of 102-in. trucks could for instance be allowed on multilane divided highways with 11-foot lanes. These lanes should gradually be widened to allow for the safe and tension-free operation of 102-in. trucks.

(C) Although no change from the AASHTO policy is expected, adherence to the existing SDHPT policy of 12 feet lane width will be necessitated if scenarios C or D is implemented. Table 15 shows the current AASHTO standards for two-lane rural highways, while the SDHPT values are shown in Tables 17 and 18.

For multilane highways the question of minimum lane width when the operation of 102-in. vehicles is allowed is difficult, but past research indicated that there should be a gradual modification of lane width to 12 feet, should 102-in. vehicles be allowed to operate on these highways. This will be in line with the fact that operators will not switch overnight to 102-in. vehicles from their existing 96-in. vehicles.

TABLE 15. MINIMUM WIDTHS OF SURFACING FOR 2-LANE HIGHWAYS

Design Speed, mph	Minimum widths of surfacing, in feet, for design volumes of *				
	Current ADT 50-250	Current ADT 250-400	Current ADT 400-750		
			DHV 100-200	DHV 200-400	DHV 400 and over
30	20	20	20	22	24
40	20	20	22	22	24
50	20	20	22	24	24
60	20	22	22	24	24
70	20	22	24	24	24
75	24	24	24	24	24
80	24	24	24	24	24

*For design speeds of 30, 40, and 50 mph, surfacing widths that are two feet narrower may be used on minor roads with few trucks.

(Ref 3)

3.2. WIDTH OF SHOULDERS

(A) Shoulders are mainly provided (Ref 3) to accommodate stopped vehicles, for emergency use, and for lateral support of the base and surface courses.

(B) In order to accommodate stopped vehicles, AASHTO recommends that the vehicles should clear the pavement edge by at least a foot and that a two-foot working space be provided (Ref 3). Widths of the standard AASHTO vehicles vary from 7.0 feet to 8.5 feet (Refs 2 and 3). By using the standard widths and clearances required, AASHTO recommends that for heavily travelled and high-speed highways the usable shoulder width should at least be 10 feet but preferably 12 feet wide (Ref 3).

Since the maximum width of vehicles proposed for scenarios A, B, C, or D is less than or equal to 8.5 feet, no change in AASHTO policy is expected.

The following relationships between shoulder width and accident frequency have been found (Ref 10):

(1) On multilane divided highways the accident rate increases as the left shoulder width increases.

(2) On multilane undivided and divided highways, right shoulders that will not accommodate a parked vehicle off the travelled way, increase the accident rate.

(3) On tangents, as the right shoulder width increases beyond the width necessary to accommodate a parked vehicle, the safety benefits become insignificant.

(4) As the right shoulder width increases on curves, the accident rate decreases.

(5) Paved right shoulders produce fewer accidents than unpaved right shoulders.

The capacity of a highway is reduced if there are restrictive lateral clearances (Ref 3). For obstructions further than 6 feet away from the pavement edge, no reduction in capacity is experienced (Ref 3). By considering capacities, accident costs, construction costs and other relevant costs for various shoulder types and widths, a cost beneficial design can be obtained.

General tables for shoulder width versus traffic volume are provided by AASHTO and the SDHPT (Refs 3 and 20). See Tables 16, 17, and 18.

(C) As the maximum vehicle width proposed in all four scenarios is less than or equal to the standard vehicle width used by AASHTO, no change in AASHTO policy is expected. The general shoulder widths as proposed by AASHTO will be the same as before but more emphasis may be placed on a cost benefit design.

TABLE 16. WIDTHS OF SHOULDERS FOR 2-LANE RURAL HIGHWAYS

Design volume		Usable shoulder width, feet	
Current ADT	DHV	Minimum	Desirable
50-250	---	4	6
250-400	---	4	8
400-750	100-200	6	10
---	200-400	8	10
---	400 and over	10	12

(Ref 3)

3.3. GUARDRAILS (OR GUARDFENCES)

(A) Guardfences are installed to protect errant vehicles from entering or reaching hazards (Refs 3, 13, and 14). But according to Refs 13 and 14, the designer should first strive to eliminate all traffic barriers, because longitudinal barriers afford only a relative degree of protection to vehicle occupants. The installation of traffic barriers may increase the frequency of accidents.

Guardfences protect the vehicles by containing and redirecting the vehicle on impact with some damage to the vehicle and some damage to the rail. However, the vehicle may straddle the rail and crush it to the ground, with the deceleration action of the posts bringing the vehicle to a stop with

TABLE 17. STANDARDS OF DESIGN FOR TWO-LANE RURAL HIGHWAYS

HIGHWAY CLASS	HIGH VOLUME (HV)		MODERATE VOLUME (MV)		LOW VOLUME (LV)					
Design Year ADT (vpd)	4400 - 7500		2200 - 4400		Less than 2200					
Design Year DHV (pcph)	750 - 1400		475 - 750		400 or less					
Current Year ADT (vpd)	-		-		750 - 1500		400 - 1100		400 or less	
Current Year DHV (pcph)	-		-		200 - 400		100 - 200		100 or less	
Design Speed (mph)	Des.	Min.	Des.	Min.	Des.	Min.	Des.	Min.	Des.	Min.
Flat	80	60	80	60	80	50	80	50	80	50
Rolling	70	60	70	50	70	40	70	40	70	40
Structure Widths (ft.)	44	30	44	30	40	30	36	30	34	30
Lane Widths (ft)	12	12	12	12	12	12	12	12	12	12
Usable Shoulder Width (ft)	10	8	10	8	8	8	6	6	4	4
Usual Surf. Shoulder Wd. (ft)	10	8	10	8	4	4	4	4	4	4
Usual Min. Roadside Cl. (ft)	30		30		16		16		16	
Right-of-Way	For minimum right-of-way requirements, see Figures 4-31 and 4-32									

(Ref 20)

TABLE 18. STANDARDS OF DESIGN FOR MULTI-LANE RURAL HIGHWAYS (NON-CONTROLLED ACCESS)

HIGHWAY CLASS		CLASS 6L		CLASS 4L		CLASS 4L UNDIVIDED	
Average Daily Traffic (ADT		20,000 or more		5000 to 20,000		Up to 7500	
Design Hourly Volume (DHV)		1600 to 2400		400 to 1600		Up to 600	
Design Speed		Des.	Min.	Des.	Min.	Des.	Min.
Flat		80	60	80	60	80	60
Rolling		70	60	70	60	70	60
Mountainous (Use AASHO Standards)							
Lane Width, Ft				12			
Median Width, Ft	Narrow	16	4	16	4	0	
	Depressed	76	48	76	48		
Shoulder Outside, Ft		10	8	10	8	10	8
Shoulder Inside, Ft		4	2	4	2	Not Applicable	
Bridge Width, Ft	Narrow Med.	108	92	84	68	68	64
	Depressed Med.	50	42	38	30		

(Ref 20)

considerable damage to both vehicle and rail, but with passengers and driver uninjured (Ref 13).

Data indicate that the area within 30 feet of the travelled way is critical for an out-of-control vehicle leaving the road. This in combination with an indication that the vehicle may travel 400 feet along the roadway after leaving the road is used to determine the position of the guardfence (Refs 13 and 14). Guardfences should be a maximum distance from the edge of the pavement (Ref 13), and shoulders should normally be 2 feet wider where guardfences are used (Ref 3).

(B) The guardfence must protect, on impact, the vehicle from hazardous features. Vehicle characteristics used to evaluate the performance of guardfences are as follows (Ref 13):

(1) Weight of vehicle = 4500 pounds,
(2) Impact speed = 60 mph,
(3) Impact angle = 25 degrees.

Vehicles of up to 31,000 pounds with an impact speed of 47 mph have been used for the testing of guardfences. But guardfences are in general designed to protect passenger cars, and the protection they give to trucks is of marginal benefit (Refs 13 and 14).

If heavier trucks are allowed, their impact momentum will increase, and guardfences designed for passenger cars will expectedly provide even less protection for these trucks.

(C) While passenger car characteristics are used for the design of guardfences, scenarios A, B, C, and D should have no effect on the existing design policy.

CHAPTER 4. INTERSECTION DESIGN ELEMENTS

4.1. MINIMUM DESIGN FOR THE SHARPEST TURNS

(A) According to AASHTO (Ref 3), it is sometimes necessary to provide for the turning of vehicles within minimum space, such as at unchannelized intersections. Then minimum turning paths of the design vehicle become highly significant. It is assumed that the vehicle is positioned 2 feet from the pavement edge at the beginning and end of the turn. The inner wheel should at no point be closer than 9 inches from the pavement edge during the turn.

(B) The expected paths that the 2-S1-2-2, 3-S2, and 3-S2-4 will follow are shown in Fig 13. This was obtained by the use of a model built according to the description of the "tracttrix integrator" (Ref 25), and the vehicle configurations as shown in Figs 1 and 2. Due to the increased offtracking characteristics of particularly the 3-S2-4 vehicle, additional pavement width will be needed to negotiate the turning path with minimum radius.

Numerous combinations of curves, spirals or tangents can be used to form the pavement edge to allow for the 3-S2-4 as design vehicle for different angles of turn. In Figs 14, 15, 16, and 17, some curve and tangent combinations that may be used for the pavement edge design are shown. These are compared with the existing AASHTO combinations (Ref 3) in Table 19.

(C) If either scenario C or scenario D is implemented, the minimum design for the sharpest turns should be such that the 3-S2-4 vehicle will be accommodated. Therefore a revision of the existing AASHTO standards can be expected.

4.2. WIDTH FOR TURNING ROADWAYS

(A) The widths required for turning roadways are classified according to the following type of operation (Ref 3).

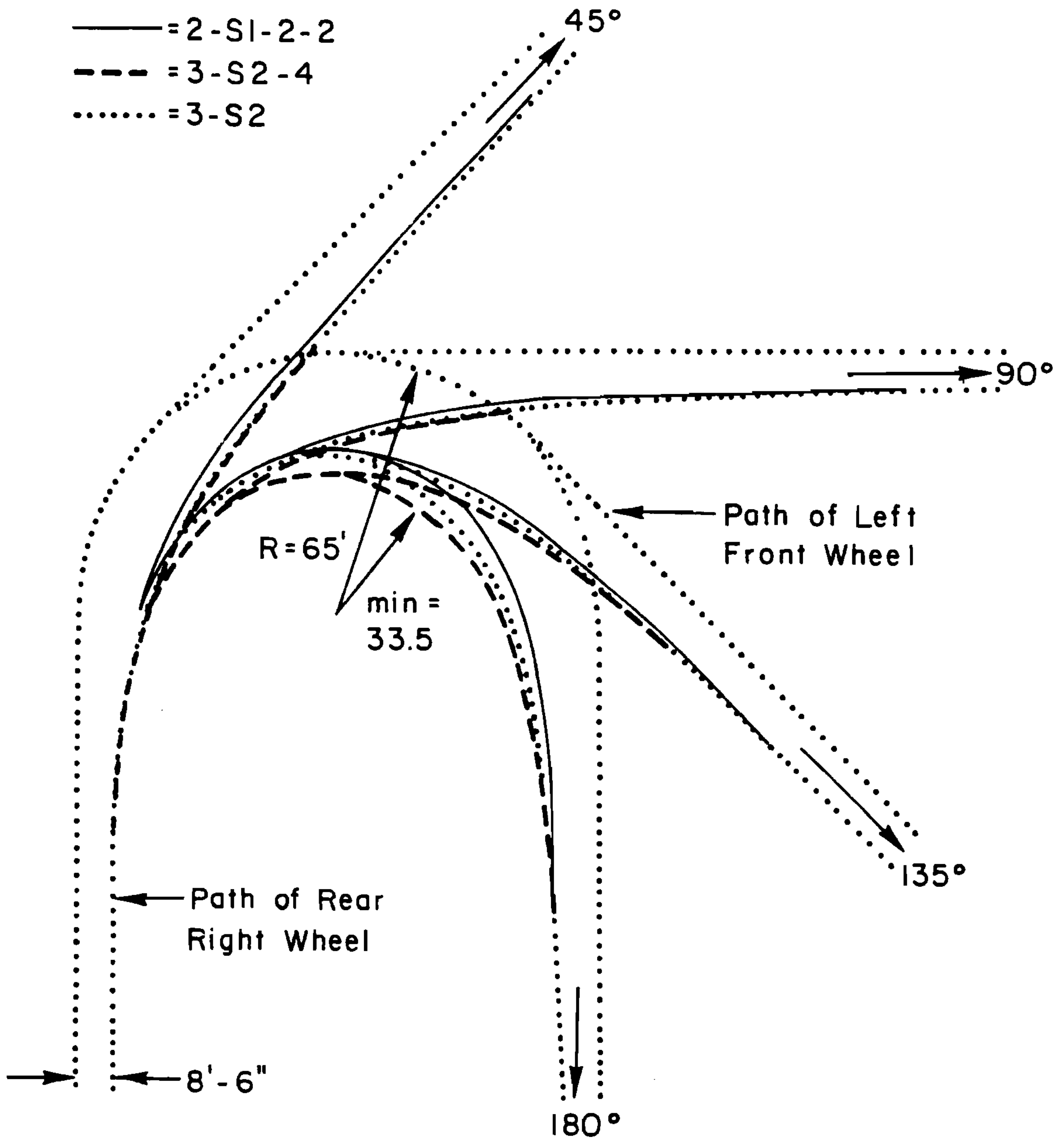


Fig 13. Offtracking for a 65-foot radius

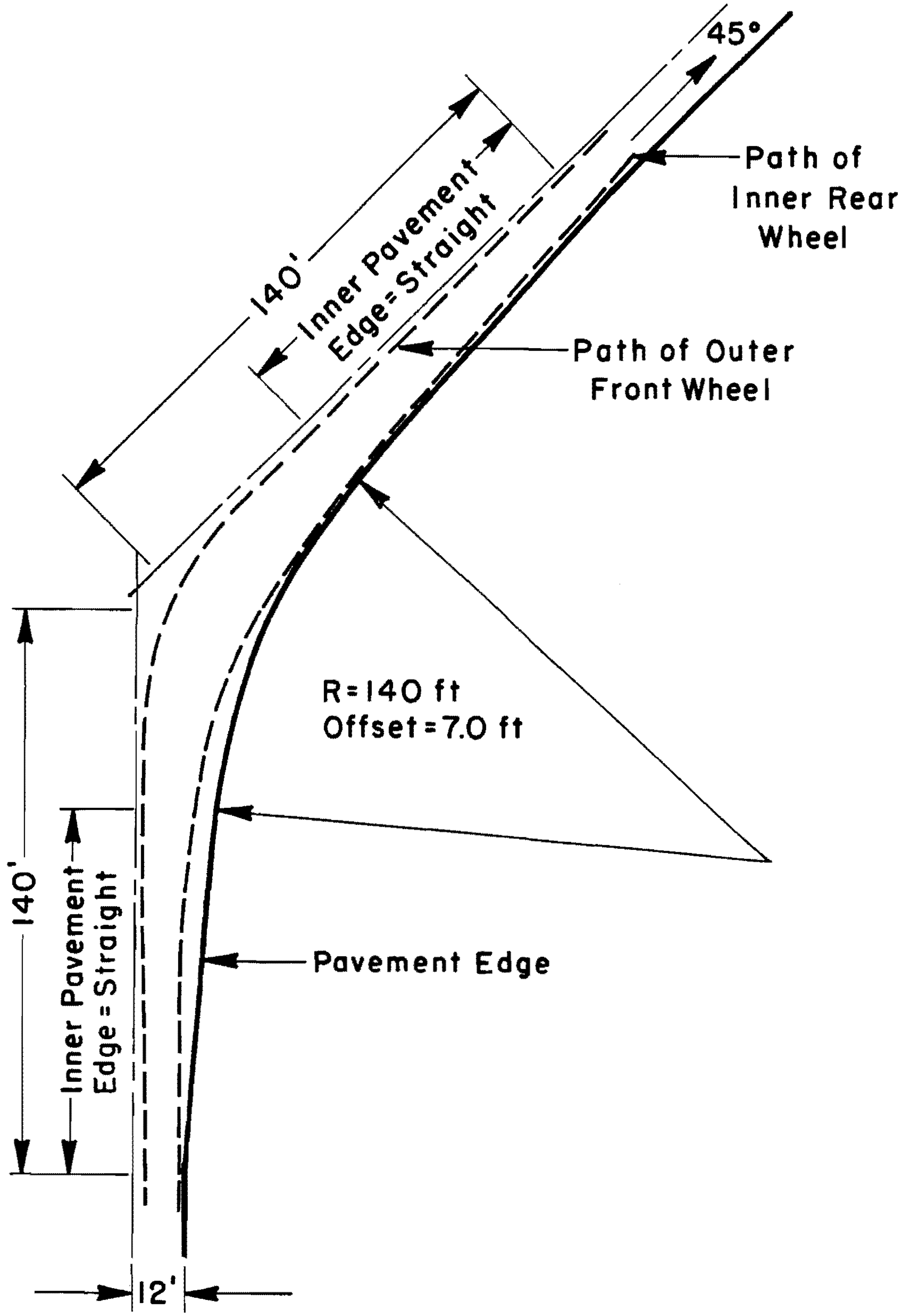


Fig 14. Minimum design for a 45-degree turn.

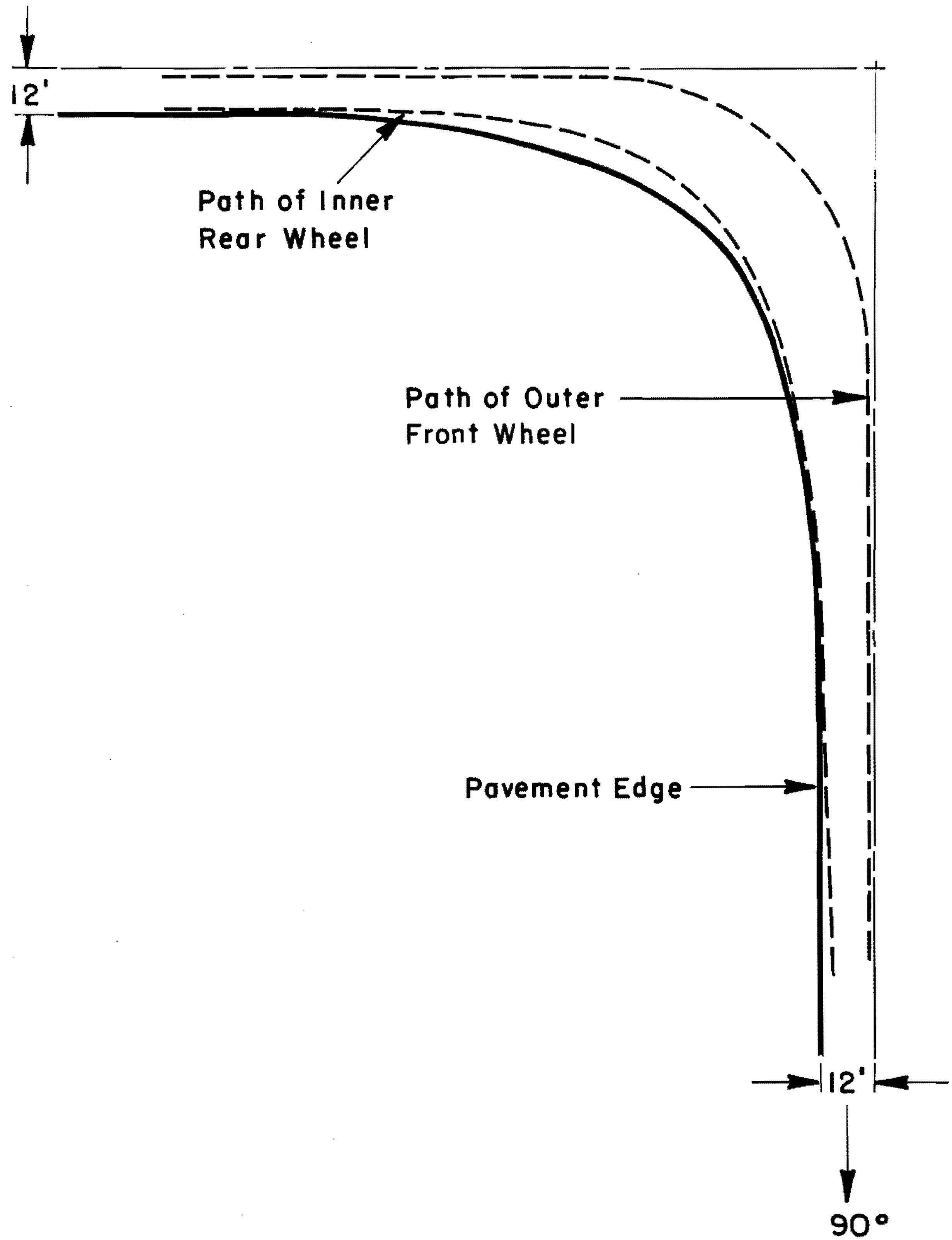


Fig 15. Minimum design for a 90-degree turn.

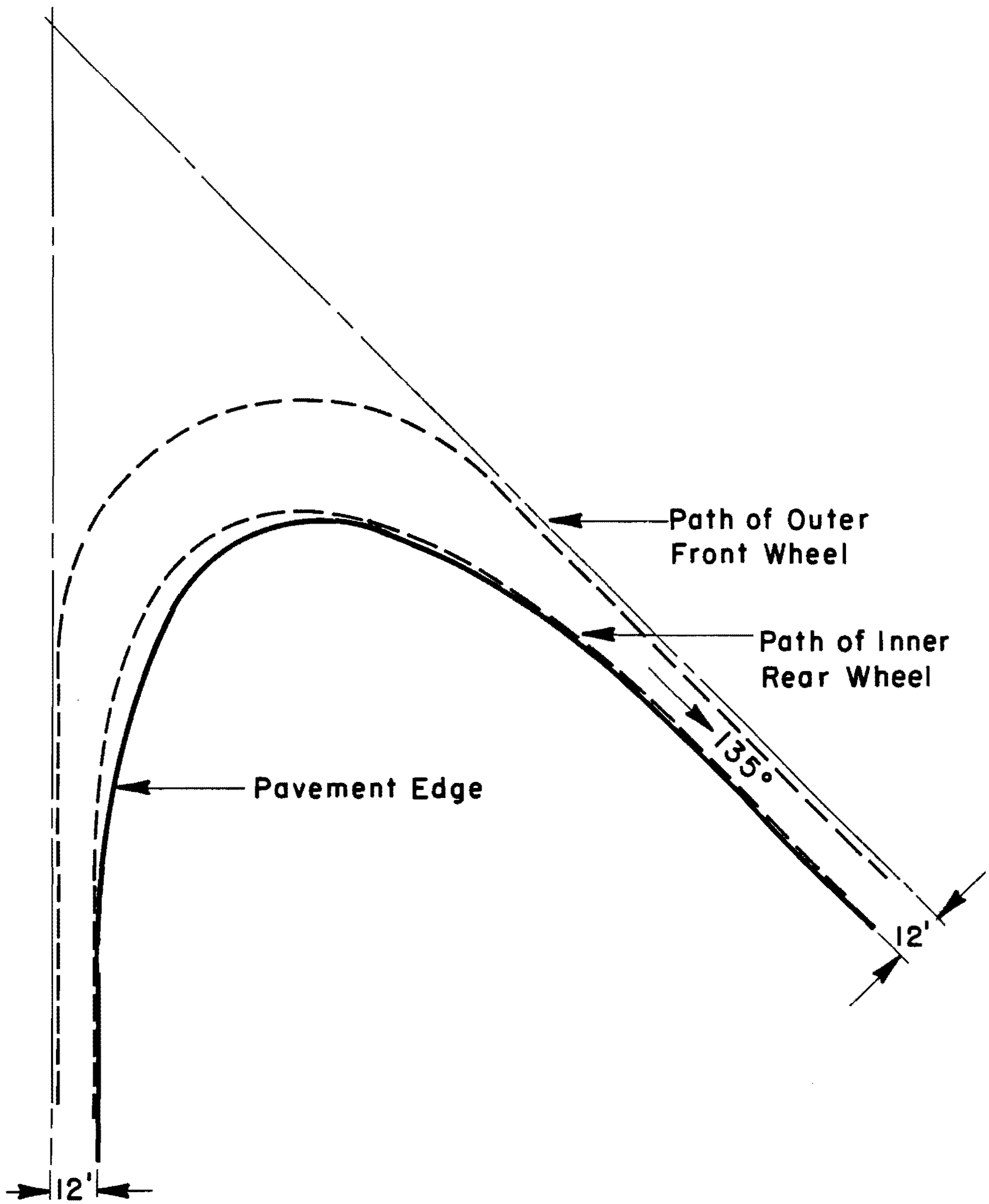


Fig 16. Minimum design for a 135-degree turn.

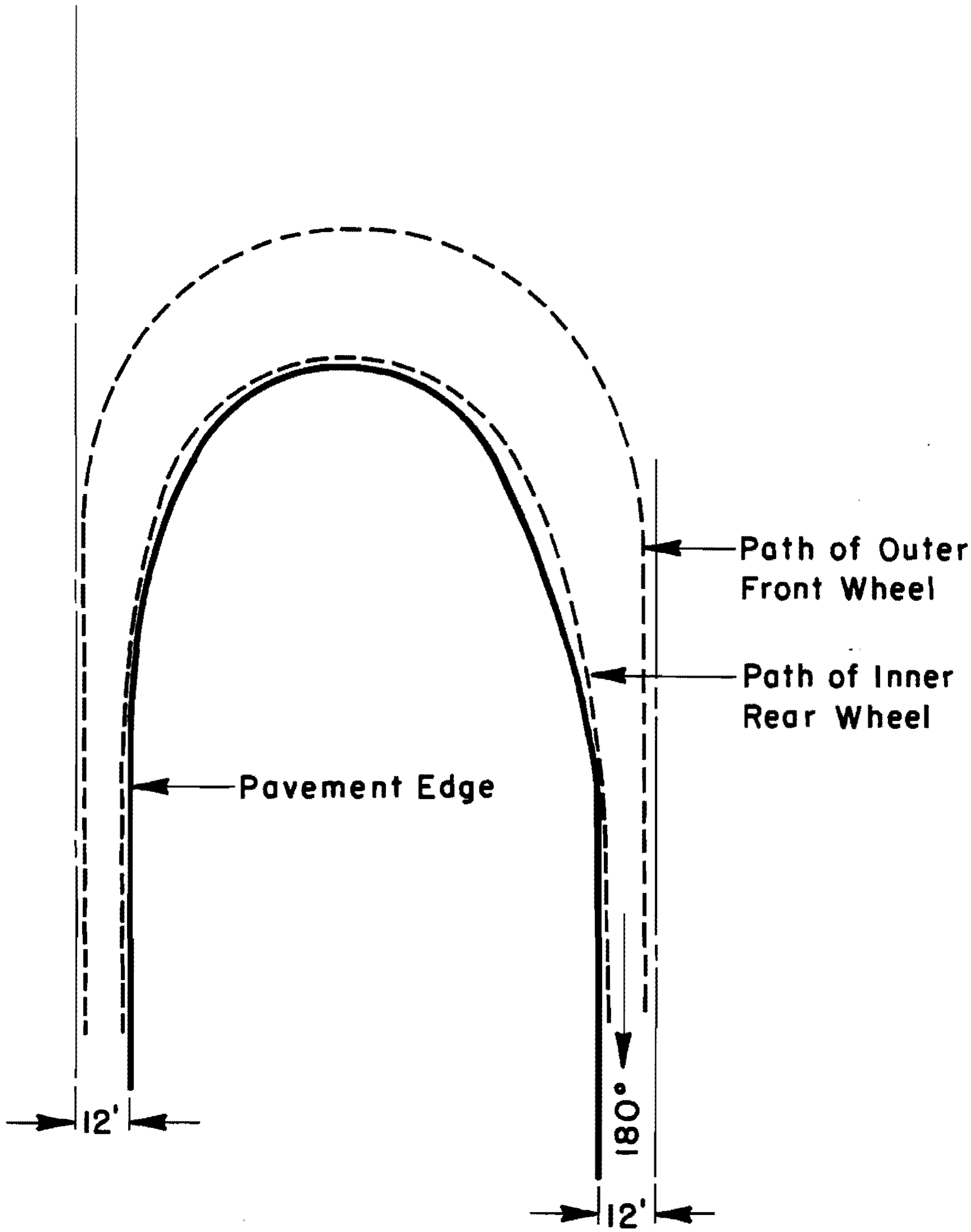


Fig 17. Minimum design for a 180-degree turn.

TABLE 19. MINIMUM EDGE OF PAVEMENT DESIGN FOR TURNS AT INTERSECTIONS

Design Vehicle	Angle of Turn	Compound Curve Symmetric		Compound Curve Asymmetric	
		Radii	Offset	Radii	Offset
WB50	45	200-100-200	3.0		
3-S2-4	45	T-140-T	7.0		
WB50	90	180- 60 -180	6.0	120- 40 -200	2.0; 10.0
3-S2-4	90	240- 60 -240	14.0		
WB50	135	160- 35 -160	9.0	130- 30 -160	3.0; 14.0
3-S2-4	135	240- 45 -240	14.0		
WB50	180	130- 25 -130	9.5	100- 25 -180	6.0; 13.0
3-S2-4	180			120- 40 -240	10.0; 20.0

Note that T = Tangent section.

Case 1. One-lane, one-way operation with no provision for passing. The formula used to compute the width for Case 1 is

$$W = U + C + Z = U + 6$$

Case 2. One-lane, one-way operation with provision for passing. The formula used to compute the width for Case 2 is

$$W = 2\,(U + C) + Fa + Fb = 2U + Fa + Fb + 4$$

Case 3. Two-lane operation, either one-way or two-way. The formula used to compute the width for Case 3 is

$$W = 2\,(U + C) + Fa + Fb + Z = 2U + Fa + Fb + 10$$

See Fig 18 (Ref 3). In the above

U = track width of vehicle (out to out tires), ft.,

Fa = width of front overhang, ft ,

Fb = width of rear overhang, ft ,

C = total lateral clearance per vehicle, ft , and

Z = extra width allowance due to difficulty of driving on curves, ft.

To compute U, Fa and C the same formulas used in "pavement widening on curves" were used (Ref 3).

(B) From the above formulas it can be seen that the vehicle configuration and length will have an effect on the roadway width while weight and height do not. The maximum vehicle width proposed for scenarios C or D is 8.5 feet, and this is the same as the maximum width used for some of the AASHTO design vehicles but is 6 inches wider than permitted by Texas motor vehicle law. When using the above formulas, new widths were calculated for the 3-S2-4 and 2-S1-2-2 vehicles.

The results obtained from these calculations are shown in Table 20, while the expected paths obtained with the model are shown in Figs 19 and 20.

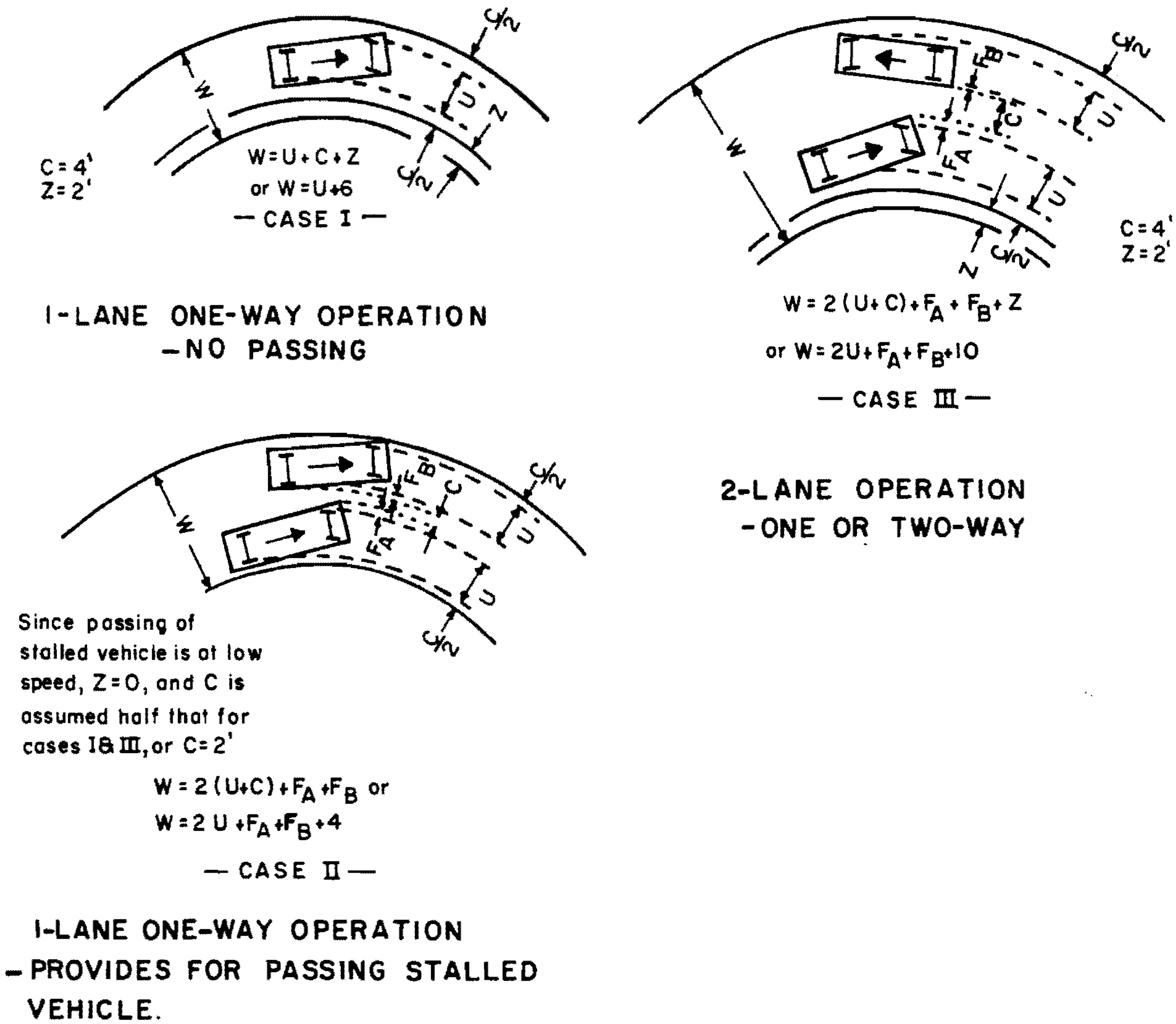


Fig 18. Pavement width on curves at intersections (Ref 3).

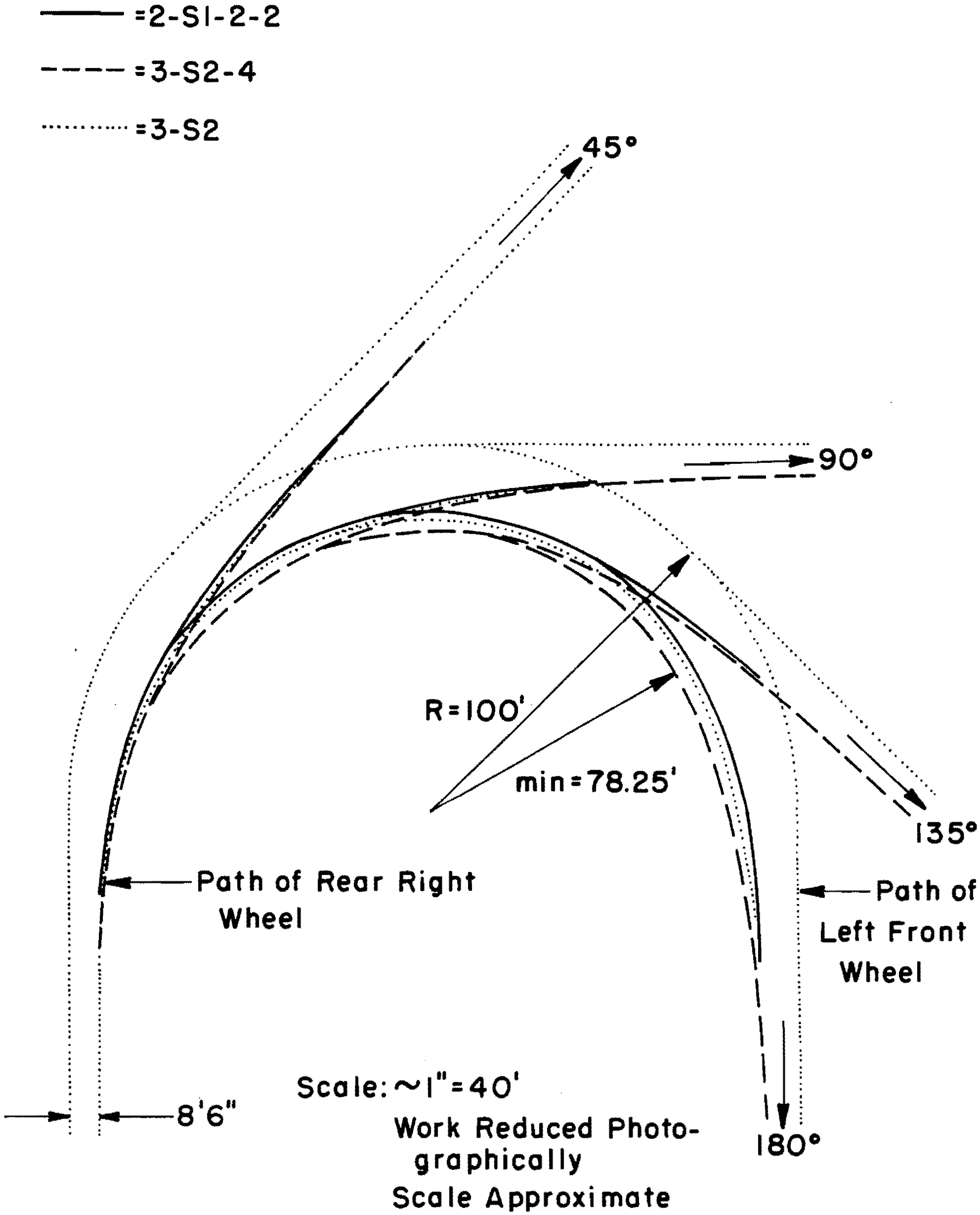


Fig 19. Offtracking for a 100-foot radius.

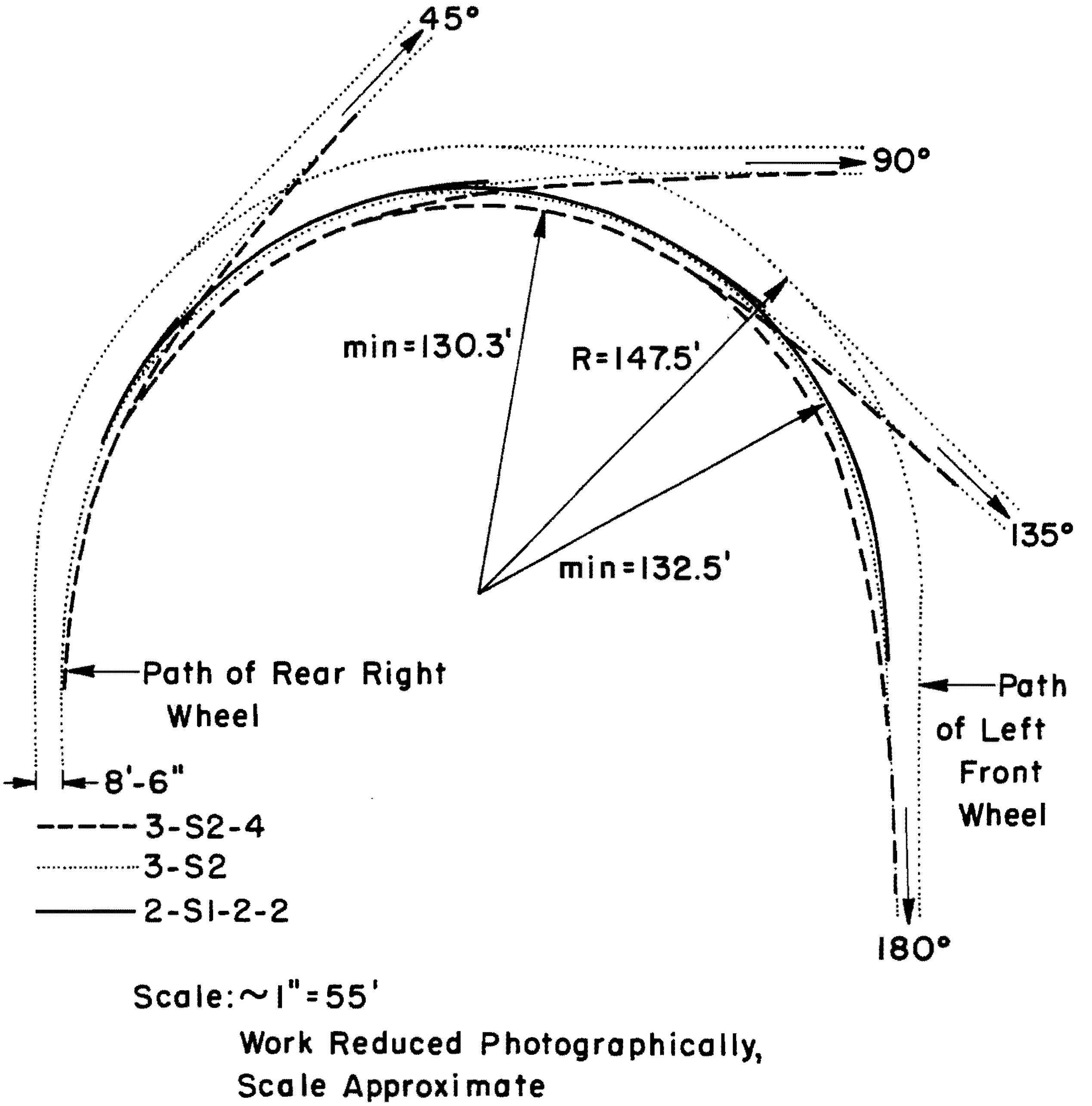


Fig 20. Offtracking for a 147.5-foot radius.

TABLE 20. DERIVED PAVEMENT WIDTHS FOR TURNING ROADWAYS FOR DIFFERENT DESIGN VEHICLES

	Case 1			Case 2			Case 4		
Radius	1	2	3	1	2	3	1	2	3
50	26	*	32	44	*	57	50	*	63
75	22	34	25	36	61	43	42	67	49
100	21	29	21	34	50	37	40	56	43
150	19	24	19	29	40	32	35	46	38
200	17	21	17	27	35	29	33	41	35
300	17	19	17	25	31	27	31	37	33
400	16	18	16	24	28	25	30	34	31
500	16	17	16	24	27	25	30	33	31
Tangent	15	15	15	21	21	21	27	27	27

Note: 1 = WB50, 2 = 3-S2-4, and 3 = 2-S1-2-2
*The 3-S2-4 cannot theoretically negotiate a 50-ft radius.

It should be borne in mind that wide pavements (say, over 30 ft) present traffic control problems (e.g. pavement markings and sign placement) and therefore radii less than 300 ft may not be a practical solution.

(C) While both vehicle types (i.e., the 3-S2-4 and 2-S1-2-2) are proposed in only scenarios C and D, no change is expected from the existing AASHTO standards for scenario B, while the values shown in Table 20 should be used if either scenario C or D is implemented.

4.3 SIGHT DISTANCE AT GRADE INTERSECTIONS

(A) AASHTO (Ref 3) considers three general cases of required sight distance at intersections, and the designer must ensure that for the different assumptions there will be unobstructed view along both roads. The three cases are:

Case 1. Enabling vehicles to adjust speed. Here only reaction + perception time and one additional second for acute braking is considered.

Case 2. Enabling vehicles to stop. Here the safe stopping sight distance plays a role.

Case 3. Enabling stopped vehicle to cross a major highway. The formula used to obtain the required sight distance is

$$d = 1.47V (J + Ta)$$

where

d = minimum sight distance along the major highway, ft ,

V = design speed of the major highway, mph,

J = sum of perception time and the time required to shift to first gear or actuate an automatic shift (seconds), and

Ta = time required to accelerate and traverse the distance S required to clear the major roadway (seconds). Ta is obtained by using Fig 21 and the distance S that the crossing vehicle must travel to clear the pavement, but

$$S = D + W + L$$

where

D = distance from near edge of pavement to front of stopped vehicle,

W = width of pavement along path of crossing vehicle, and

L = overall vehicle length.

(B) From the above it can be seen that only Case 3 will be influenced by vehicle length and acceleration ability, while it has previously been shown that the stopping sight distance will not be adversely affected by scenarios B, C, or D. If it is assumed that the acceleration ability of the 3-S2-4 and 2-S1-2-2 vehicles will be at least the same as that of the WB50 (Fig 21), then longer sight distance will be needed due to the increase in vehicle length. This assumption is affirmed by truck acceleration tests made by the Western Highway Institute (Ref 24). For scenarios C and D using the 3-S2-4 and 2-S1-2-2 vehicle, additional sight distance along the major highway will be needed, and this is shown in Fig 22.

(C) Should scenarios C or D be implemented, additional sight distance along the major highway will be required for Case 3 to compensate for increased vehicle length.

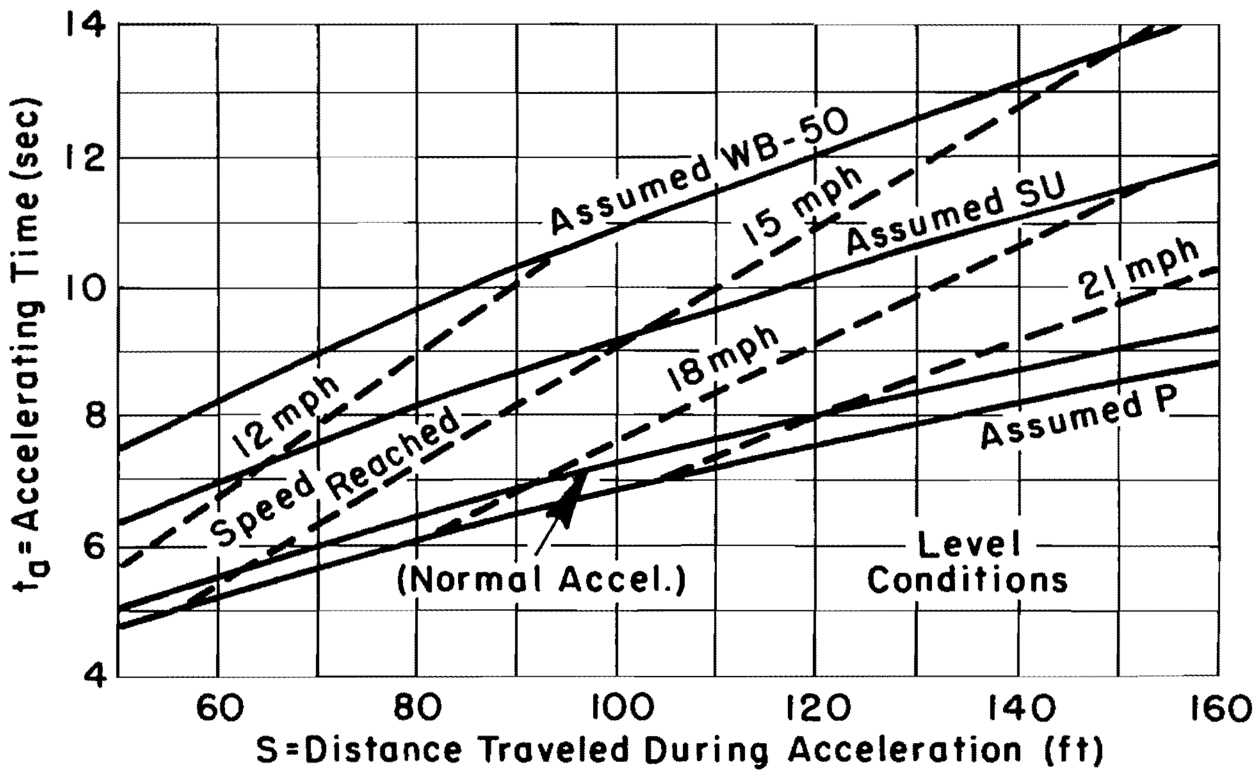


Fig 21. Data on acceleration from stop (Ref 3).

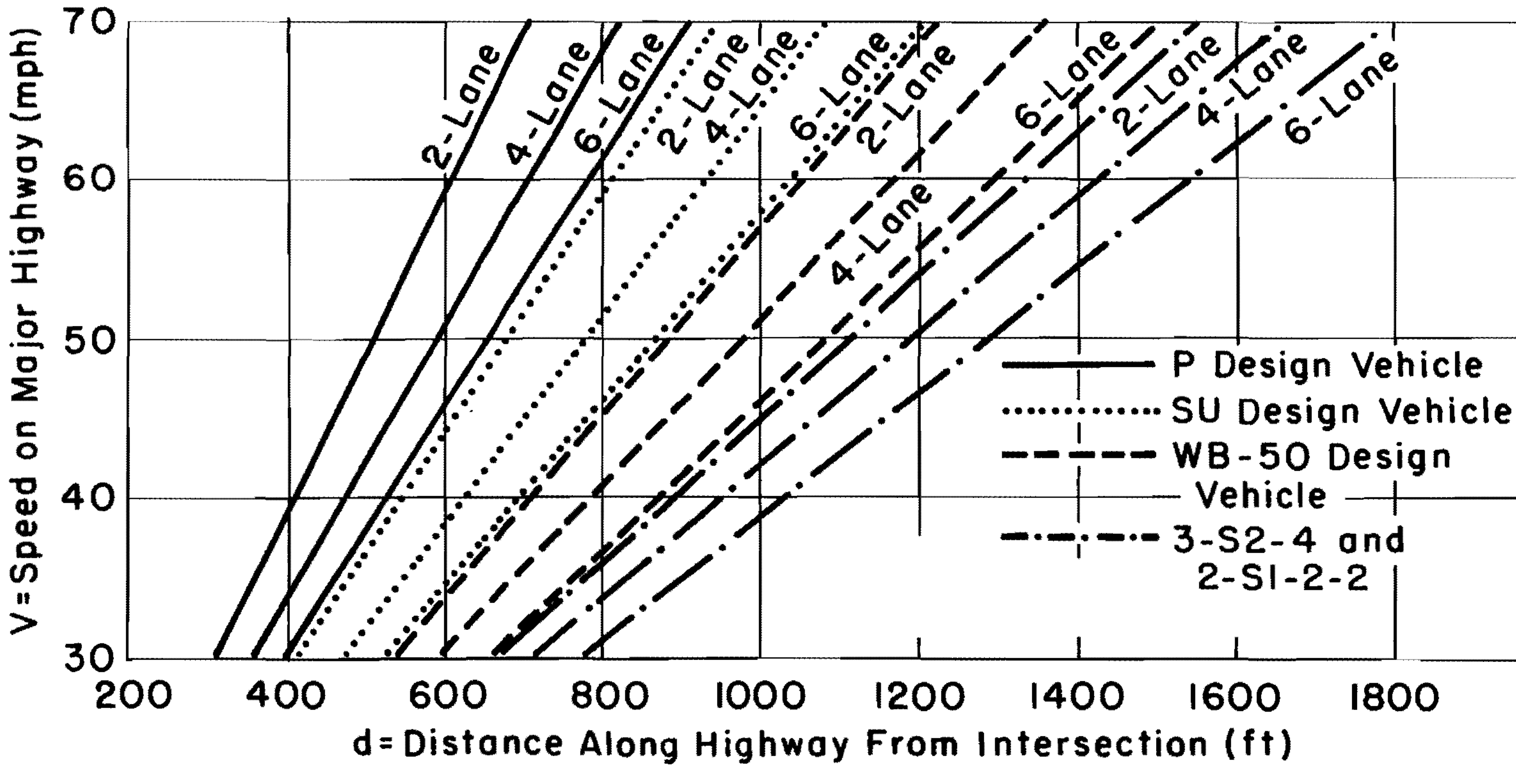


Fig. 22. Required sight distance along major highways.

4.4. MEDIAN OPENINGS

(A) The design of median openings depends upon the type of turning vehicle and the traffic volumes (Ref 3). The opening must accommodate the offtracking characteristics of the design vehicle at slow speeds (see "Minimum design for sharpest curves" for a discussion on the expected wheel paths of the 3-S2-4 and 2-S1-2-2 vehicles).

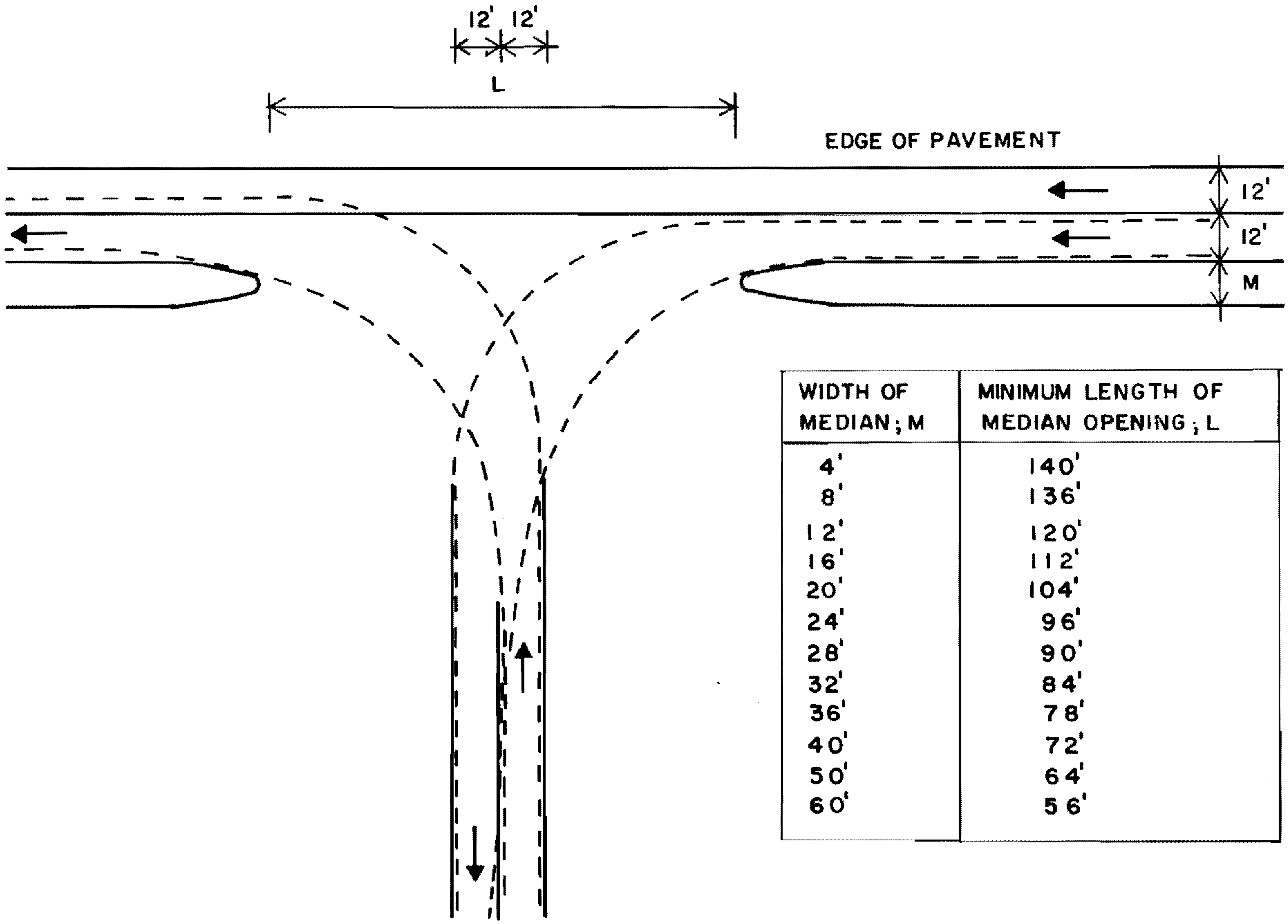
(B) By using the offtracking characteristics obtained in "Minimum design for the sharpest curves," Fig 23 was obtained. Here the minimum median opening is shown for various widths of the median. An 85-ft control radius was used as this fits the path of the turning vehicle without undue encroachment of the vehicle on the adjacent lane. A left turn from the major divided highway can be made without any encroachment.

While entering the divided highway from a left turn, the 3-S2-4 vehicle will encroach on the adjacent lane about 4 ft, but this can be minimized by swinging wide at the beginning of the turn.

(C) Should scenario C or D be introduced, a change in the design of median openings can be expected due to the increased offtracking characteristics of the 3-S2-4 vehicle.

4.5. MEDIAN LANES

(A) Median lanes are provided as deceleration and storage lanes for vehicles making left turns from a divided highway (Refs 3 and 20). The length of the lane should be sufficient to store the expected number of left-turn vehicles during a one-minute interval. AASHTO (Ref 3) further assumes that only 25 ft be allowed per turning vehicle and when doubling the arrivals per minute obtained the following required storage length as shown in Table 21. The SDHPT has the same standard.



WIDTH OF MEDIAN; M	MINIMUM LENGTH OF MEDIAN OPENING; L
4'	140'
8'	136'
12'	120'
16'	112'
20'	104'
24'	96'
28'	90'
32'	84'
36'	78'
40'	72'
50'	64'
60'	56'

Fig 23. Median openings.

TABLE 21. LEFT TURN STORAGE LENGTH (FEET) (REFS 3 AND 20)

Turning Vehicles Per Hour	Storage Length, feet
30	25
60	50
100	100
200	175
300	250

Since trucks are not considered by AASHTO in designing the storage length, an increase in truck dimensions should have no influence on the design of median storage lanes. For the above storage lengths and a 65-ft vehicle, storage space would have been provided for the 65-ft truck when the number of left-turning vehicles is equal to or greater than 100 per hour. If scenario C or D is implemented, the maximum truck length will be 105 ft., and this truck can also be accommodated in the storage space required when the number of turning vehicles is equal to or greater than 100 per hour. This can be accomplished by taking the taper into account; however, the length available for passenger vehicles will be reduced.

(B) Since the design vehicle is the passenger car, no change in AASHTO policy is expected should scenario C or D be implemented. But the composition of traffic should be considered when designing storage space and larger design vehicles should be used if their numbers justify it.

CHAPTER 5. COST ESTIMATES

In order to derive cost estimates for the various elements with an acceptable interval of confidence, it was necessary to obtain information on a representative group of each road functional or system class. This information was obtained either by collecting data manually from "as built" plans and doing a statistical test on the confidence interval obtained from the sample, or by using information provided by the SDHPT.

The Federal Highway Administration required a diversity of information from the SDHPT concerning the following rural functional road classes (Ref 21):

(1) Interstate;
(2) Principal arterials: other;
(3) Minor arterials;
(4) Major collectors; and
(5) Minor collectors.

The sample sizes required for the HPMS were based on "a 90-5 precision level for the volume groups of the principal arterial system, 90-10 for the minor arterial system, and on an 80-10 precision level for the collector system" (Ref 21).

This information was made available for the use in this study and proved to be invaluable. Whenever use of this information (hereafter referred to as the HPMS information), or the extended form, is made to derive a cost estimate, no statistical testing on the sample size adequacy will be done. This was done by the Texas State Department of Highways and Public Transportation prior to the collecting of the required information. For all other estimates statistical testing will be done to ensure an adequate sample size.

As it was necessary to distinguish between the following road systems, a manual identification of the HPMS section identities was performed for

(1) Interstate,
(2) US and State routes, and

(3) Farm to Market roads.

Note that only the following items were taken into account when the cost estimates were made:

(1) Widening of the existing pavement with the exclusion of such items as grading, median barriers, curbs, guardrails, sign relocation, earth works, additional right of way, culvert extension, or pavement markings. (See Appendix.)

(2) Widening of existing bridges.

5.1. STOPPING SIGHT DISTANCE

To increase the truck size or weight should have no cost effect on the above design element.

5.2. PASSING SIGHT DISTANCE

Although more distance will be needed to overtake longer trucks, the pavement markings will not be influenced by an increase in truck length or weight, according to the existing "Manual on Uniform Traffic Control Devices" (Ref 1). Therefore no cost estimate is involved here.

5.3. PAVEMENT WIDENING ON CURVES

Should scenarios B, C, or D be implemented, additional pavement widths must be added on restrictive curves for scenarios C or D. As the HPMS did not require the lengths of restrictive curves, these were manually obtained for all the HPMS's rural sections. This was added to the HPMS data, and will be referred to as the extended HPMS information.

Table 6, average cost figures obtained from the Texas State Department of Highways and Public Transportation (see Appendix), and the extended HPMS information were used to derive the cost estimates shown in Table 22.

5.4. CRITICAL LENGTHS OF GRADES

To increase the size or weight of trucks should have no effect on the above design element. Therefore no cost estimate is involved here.

TABLE 22. COST ESTIMATES TO WIDEN PAVEMENTS ON RESTRICTED CURVES (IN 1979 DOLLARS)

	Length of Section in Miles	Additional Area Sq. Yd.		Length of System in Miles	Additional Area For System Sq. Yd.		Scenario C	Scenario D
		Scenario 2-S1-2-2	Scenario 3-S2-4		Scenario 2-S1-2-2	Scenario 3-S2-4		
Interstate System	1157.97	1,763	4,146	2,214	4,000	8,000	$ 297,000	$ 297,000
U.S. and State System	4372.93	21,263	52,687	22,070	154,000	362,000	$ 5,409,000	$ 5,409,000
Farm to Market System	985.98	83,917	157,149	38,169	3,249,000	6,084,000	$28,471,000	$28,471,000
TOTAL OF ABOVE THREE	6516.88	106,943	213,982	62,453	3,407,000	6,454,000	$34,177,000	$34,177,000
Interstate System	1157.97	1,763	4,146	2,214	3,400	8,000	$ 297,000	$ 297,000
All Principal Arterials	4004.98	8,295	23,179	10,317.23	22,000	62,000	$ 1,979,000	$ 1,979,000
All Systems	6516.88	106,943	213,982	62,453	3,407,000	6,454,000	$34,177,000	$34,177,000

5.5. REST AREAS

Due to the standard layout with parallel parking, no expansion or modification of the existing facilities is anticipated. In future designs, offtracking characteristics of the 3-S2-4 should be borne in mind. To increase the size or weight of trucks will only reduce the capacity of existing rest areas and therefore no cost estimate is involved here.

5.6. LANE WIDTH

Should scenarios B, C, or D be implemented and the current SDHPT policy of a 12-ft minimum lane width be implemented, additional pavement width must be added. The extended HPMS information and average cost figures (Appendix 1) were used to obtain the estimates shown in Tables 23 through 27. Only bridges less than 1,000 ft were used to calculate the average length on the different road classes. With the aid of the computer, the following was obtained.

(1) Identification of sections with restrictive widths and the length thereof.

(2) Total additional area required.

(3) Number of bridges to be widened.

A distinction between flexible or rigid pavements and the class of road were made in order to derive the cost estimates.

Note that while the current SDHPT policy was used to obtain these cost estimates, they also apply to scenario A. The average cost figures for scenario A are more or less equal to those of scenario C and therefore the total cost to upgrade the existing highway system to current policy, will be the same as that for scenario C.

5.7. WIDTH OF SHOULDERS

If any of scenarios B, C, or D are implemented, the existing SDHPT policy of desirable shoulder widths used, additional pavement width must be added.

The extended HPMS information, average cost figures, and the existing

TABLE 23. ADDITIONAL COST TO UPGRADE LANE WIDTH TO 12 FEET FOR THE INTERSTATE SYSTEM (IN 1979 DOLLARS)

Lane Width, Feet	Number of Sections	Length of Sections in Miles	Additional Area, Sq. Yd.	Scenario B	Scenario C	Scenario D
9 R	0	0	0	0	0	0
9 F	0	0	0	0	0	0
10 R	0	0	0	0	0	0
10 F	0	0	0	0	0	0
11 R	0	0	0	0	0	0
11 F	1	1.28	1501.85	$ 39,800	$ 37,700	$ 37,700
12	137	1156.69	0	0	0	0
Section Total	138	1157.97	1501.85	$ 39,800	$ 37,700	$ 37,700
State Total		2214	2900	$ 77,000	$ 73,000	$ 73, 000
Number of Bridges on Sections	Number of Bridges on System	Sectional Additional Area Sq. Yd.	State Additional Area Sq. Yd.	Scenario B State Total	Scenario C State Total	Scenario D State Total
1589	2824	42	80	43,000	43,000	43,000
GRAND TOTAL				$120,000	$116,000	$116,000

TABLE 24. ADDITIONAL COST TO UPGRADE LANE WIDTH TO 12 FEET FOR ALL U.S. AND STATE HIGHWAY SYSTEMS (IN 1979 DOLLARS)

Lane Width, Feet	Number of Sections	Length of Sections in Miles	Additional Area, Sq. Yd.	Scenario B	Scenario C	Scenario D
9 R	1	2.86	10,067.19	$ 313,000	$ 313,000	$ 313,000
9 F	4	58.49	228,926.47	$ 3,074,000	$ 2,770,000	$ 2,770,000
10 R	1	4.20	9,855.99	$ 306,000	$ 306,000	$ 306,000
10 F	34	226.01	579,667.02	$ 7,785,000	$ 7,014,000	$ 7,014,000
11 R	0	0	0	0	0	0
11 F	55	506.52	785,889.74	$ 10,554,000	$ 9,510,000	$ 9,510,000
12	418	3574.85	0	0	0	0
Section Total	513	4372.93	1,614,406.40	$ 22,032,000	$ 19,913,000	$ 19,913,000
State Total		22,070	10,419,000	$142,042,000	$128,355,000	$128,355,000
Number of Bridges on Sections	Number of Bridges on System	Sectional Additional Area Sq. Yd.	State Additional Area Sq. Yd.	Scenario B State Total	Scenario C State Total	Scenario D State Total
1832	9678	14,550	76,900	41,526,000	41,526,000	41,526,000
GRAND TOTAL				$183,568,000	$169,881,000	$169,881,000

TABLE 25. ADDITIONAL COST TO UPGRADE LANE WIDTH TO 12 FEET FOR ALL FARM TO MARKET ROADS (IN 1979 DOLLARS)

Lane Width, Feet	Number of Sections	Length of Sections in Miles	Additional Area, Sq. Yd	Scenario B	Scenario C	Scenario D
9 R	1	4.00	14,079.98	$ 437,000	$ 437,000	$ 437,000
9 F	37	220.58	780,598.06	$ 3,653,000	$ 3,653,000	$ 3,653,000
10 R	1	5.27	12,366.92	$ 384,000	$ 384,000	$ 384,000
10 F	105	605.89	1,421,805.71	$ 6,654,000	$ 6,654,000	$ 6,654,000
11 R	0	0	0	0	0	0
11 F	7	33.01	38,731.29	$ 181,000	$ 181,000	$ 181,000
12	24	117.23	0	0	0	0
Section Total	175	985.98	2,267,581.97	$ 11,309,000	$ 11,309,000	$ 11,309,000
State Total		38,169	87,782,000	$437,791,000	$437,791,000	$437,791,000
Number of Bridges on Section	Number of Bridges on System	Sectional Additional Area Sq. Yd.	State Additional Area Sq. Yd.	Scenario B State Total	Scenario C State Total	Scenario D State Total
189	8158	8,425	363,600	$183,255,000	$183,255,000	$183,255,000
GRAND TOTAL				$621,046,000	$621,046,000	$621,046,000

R = Rigid Pavement
F = Flexible Pavement

TABLE 26. ADDITIONAL COST TO UPGRADE LANE WIDTH TO 12 FEET FOR ALL PRINCIPAL ARTERIALS (IN 1979 DOLLARS)

Lane Width, Feet	Number of Sections	Length of Sections in Miles	Additional Area, Sq. Yd.	Scenario B	Scenario C	Scenario D
9 R	0	0	0	0	0	0
9 F	3	36.63	151,980.14	$ 2,041,000	$ 1,839,000	$ 1,839,000
10 R	1	4.20	9,855.99	$ 306,000	$ 306,000	$ 306,000
10 F	2	16.48	58,501.74	$ 786,000	$ 708,000	$ 708,000
11 R	0	0	0	0	0	0
11 F	29	287.68	471,228.78	$ 6,348,000	$ 5,722,000	$ 5,722,000
12	429	3,659.90	0	0	0	0
Section Total	464	4,004.89	691,566.64	$ 9,481,000	$ 8,575,000	$ 8,575,000
State Total		10,317.23	1,962,000	$ 26,880,000	$ 24,309,000	$ 24,309,000
Number of Bridges on Sections	Number of Bridges on System	Sectional Additional Area Sq. Yd.	State Additional Area Sq. Yd.	Scenario B State Total	Scenario C State Total	Scenario D State Total
2873	6676	6,435	19,300	$ 10,422,000	$ 10,422,000	$ 10,422,000
GRAND TOTAL				$ 37,302,000	$ 34,731,000	$ 34,731,000

R = Rigid Pavement
F = Flexible Pavements

TABLE 27. ADDITIONAL COST TO UPGRADE LANE WIDTH TO 12 FEET FOR THE "ALL SYSTEMS" COMBINATION (IN 1979 DOLLARS)

Lane Width, Feet	Number of Sections	Length of Sections in Miles	Additional Area, Sq. Yd.	Scenario B	Scenario C	Scenario D
9 R	2	6.86	24,147.17	$ 750,000	$ 750.000	$ 750,000
9 F	41	279.07	1,009,524.53	$ 6,727,000	$ 6,423,000	$ 6,423,000
10 R	2	9.47	22,222.91	$ 690,000	$ 690,000	$ 690,000
10 F	139	831.90	2,001,472.73	$ 14,439,000	$ 13,668,000	$ 13,668,000
11 R	0	0	0	0	0	0
11 F	63	540.81	826,122.88	$ 10,775,000	$ 9,729,000	$ 9,729,000
12	579	4,848.77	0	0	0	0
Section Total	826	6,516.88	3,883,490.22	$ 33,381,000	$ 31,260,000	$ 31,260,000
State Total		62,453	98,204,000	$579,910,000	$566,219,000	$566,219,000
Number of Bridges on Sections	Number of Bridges on System	Sectional Additional Area Sq. Yd.	State Additional Area Sq. Yd.	Scenario B State Total	Scenario C State Total	Scenario D State Total
3610	20660	23,017	440,580	$224,924,000	$224,824,000	$224,824,000
GRAND TOTAL				$804,734,000	$791,043,000	$791,043,000

R = Rigid Pavement
F = Flexible Pavement

SDHPT policy on shoulder width were used to obtain the estimates shown in Tables 28 through 32. The computer was used to identify

(1) Sections with restrictive width and the lengths.

(2) Total additional area required.

(3) Number of bridges to be widened.

A distinction between flexible and rigid pavements, and the class of road were made in order to derive the cost estimate.

Note that here as for "Lane width" the current SDHPT policy was used to obtain cost estimates for scenarios B, C, and D. Therefore to upgrade the existing road network to current SDHPT policy (scenario A), additional cost equivalent to that of scenario C will be needed.

5.8. GUARDRAILS

An increase in truck size or weight should not have any effect on the design of guardrails since passenger vehicle characteristics are used rather than characteristics of trucks.

5.9. INTERSECTION DESIGN ELEMENTS

Because of the close relationship of the five design elements, no separate cost estimates will be made for individual elements. The five will be treated in their entirety. As information on the intersections had to be manually retrieved, the following methodology was envisaged to eliminate bias and reduce the variance.

(1) Sections of road and the included intersections were randomly selected.

(2) Due to the expected big variance between different intersection types, the intersections were divided in the following classes:

(a) Interstate with Interstate routes,

(b) Interstate with US or State routes,

(c) Interstate with FM routes,

(d) US or State with US or State routes,

(e) US or State with FM routes, and

TABLE 28. ADDITIONAL COST TO UPGRADE SHOULDER WIDTH TO EXISTING SDHPT POLICY FOR THE INTERSTATE SYSTEM (IN 1979 DOLLARS)

Shoulder Width, Feet	Number of Sections	Length of Sections in Miles	Additional Area, Sq. Yd.	Scenario B	Scenario C	Scenario D
4 F	0	0	0	0	0	0
6 R	0	0	0	0	0	0
6 F	0	0	0	0	0	0
8 R	0	0	0	0	0	0
8 F	0	0	0	0	0	0
10 R	0	0	0	0	0	0
10 F	0	0	0	0	0	0
Divided R	1	2.41	2,827.73	$105,000	$105,000	$105,000
Divided F	1	4.07	9,550.66	$253,000	$240,000	$240,000
Section Total	138	1157.97	12,[illegible].39	$358,000	$345,000	$345,000
State Total		2214	24,000	$684,000	$660,000	$660,000

Number of Bridges on Sections	Number of Bridges on System	Section's Additional Area Sq. Yd.	State's Additional Area Sq. Yd.	Scenario B State Total	Scenario C State Total	Scenario D State Total
1589	2824	125	250	$135,000	$135,000	$135,000
GRAND TOTAL				$819,000	$819,000	$819,000

R = Rigid Pavement F = Flexible Pavement

TABLE 29. ADDITIONAL COST TO UPGRADE SHOULDER WIDTH TO EXISTING SDHPT POLICY FOR ALL U.S. AND STATE ROADS

Shoulder Width, Feet	Number of Sections	Length of Sections in Miles	Additional Area, Sq. Yd.	Scenario B	Scenario C	Scenario D
4 F	12	81.32	75,292.58	$ 1,011,000	$ 911,000	$ 911,000
6 R	0	0	0	0	0	0
6 F	8	65.04	175,119.5	$ 2,352,000	$ 2,119,000	$ 2,119,000
8 R	1	4.20	4,927.86	$ 153,000	$ 153,000	$ 153,000
8 F	25	190.46	960,382.34	$ 12,898,000	$ 12,652,000	$ 12,652,000
10 R	4	16.21	122,633.32	$ 3,808,000	$ 3,808,000	$ 3,808,000
10 F	258	2,296.72	7,853,718.20	$105,475,000	$ 95,030,000	$ 95,030,000
Divided R	3	11.13	21,752.91	$ 676,000	$ 676,000	$ 676,000
Divided F	9	57.76	198,616.23	$ 2,667,000	$ 2,403,000	$ 2,403,000
Section Total	513	4,372.93	9,412,442.94	$129,040,000	$117,752,000	$117,752,000
State Total		22,070	49,483,000	$681,631,000	$626,555,000	$626,555,000
Number of Bridges on Sections	Number of Bridges on System	Section's Additional Area Sq. Yd.	State's Additional Area Sq. Yd.	Scenario B State Total	Scenario C State Total	Scenario D State Total
1832	9678	70,455	375,950	$203,013,000	$203,013,000	$203,013,000
GRAND TOTAL				$884,644,000	$829,568,000	$829,568,000

TABLE 30. ADDITIONAL COST TO UPGRADE SHOULDER WIDTH TO EXISTING SDHPT POLICY FOR THE FARM TO MARKET SYSTEM

Shoulder Width, Feet	Number of Sections	Length of Sections in Miles	Additional Area, Sq. Yd.	Scenario B	Scenario C	Scenario D
4 F	89	486.32	1,080,273.2	$ 5,056,000	$ 5,056,000	$ 5,056,000
6 R	0	0	0	0	0	0
6 F	26	186.49	986,019.6	$ 4,615,000	$ 4,615,000	$ 4,615,000
8 R	0	0	0	0	0	0
8 F	18	115.31	765,574.36	$ 3,583,000	$ 3,583,000	$ 3,583,000
10 R	1	5.27	24,733.16	$ 768,000	$ 768,000	$ 768,000
10 F	19	55.49	364,485.65	$ 1,706,000	$ 1,706,000	$ 1,706,000
Divided R	0	0	0	0	0	0
Divided F	0	0	0	0	0	0
Section Total	175	985.98	3,221,085.97	$ 15,728,000	$ 15,728,000	$ 15,728,000
State Total		38,169	124,694,000	$608,858,000	$608,858,000	$608,858,000
Number of Bridges on Sections	Number of Bridges on System	Section's Additional Area Sq. Yd.	State's Additional Area Sq. Yd.	Scenario B State Total	Scenario C State Total	Scenario D State Total
189	8158	25,820	1,114,400	$561,658,000	$561,658,000	$561,658,000
GRAND TOTAL				$1,170,516,000	$1,170,516,000	$1,170,516,000

R = Rigid Pavement
F = Flexible Pavement

TABLE 31. ADDITIONAL COST TO UPGRADE SHOULDER WIDTH TO EXISTING SDHPT POLICY FOR ALL PRINCIPAL ARTERIALS

Shoulder Width, Feet	Number of Sections	Length of Sections In Miles	Additional Area, Sq. Yd.	Scenario B	Scenario C	Scenario D
4 F	0	0	0	0	0	0
6 R	0	0	0	0	0	0
6 F	0	0	0	0	0	0
8 R	1	4.20	4,927.86	$ 153,000	$ 153,000	$ 153,000
8 F	6	42.64	362,429.90	$ 4,867,000	$ 4,385,000	$ 4,385,000
10 R	2	5.06	40,666.58	$ 1,263,000	$ 1,263,000	$ 1,263,000
10 F	171	1,590.90	5,270,158.54	$ 70,778,000	$ 63,769,000	$ 63,769,000
Divided R	3	9.82	20,216.48	$ 645,000	$ 645,000	$ 645,000
Divided F	9	44.77	128,100.89	$ 1,845,000	$ 1,674,000	$ 1,674,000
Section Total	464	4,004.89	5,826,500.25	$ 79,551,000	$ 71,889,000	$ 71,889,000
State Total		10,317.23	16,573,000	$226,092,000	$204,297,000	$204,297,000
Number of Bridges on Sections	Number of Bridges on System	Section's Additional Area Sq. Yd.	State's Additional Area Sq. Yd.	Scenario B State Total	Scenario C State Total	Scenario D State Total
2873	6676	40,625	121,750	$ 65,745,000	$ 65,745,000	$ 65,745,000
GRAND TOTAL				$291,837,000	$270,042,000	$270,042,000

R = Rigid Pavement
F = Flexible Pavement

TABLE 32. ADDITIONAL COST TO UPGRADE SHOULDER WIDTH TO EXISTING SDHPT POLICY FOR THE "ALL SYSTEMS" COMBINATION

Shoulder Width, Feet	Number of Sections	Length of Sections In Miles	Additional Area, Sq. Yd.	Scenario B	Scenario C	Scenario D
4 F	101	567.64	1,155,565.78	$ 6,067,000	$ 5,967,000	$ 5,967,000
6 R	0	0	0	0	0	0
6 F	34	251.53	1,161,139.10	$ 6,967,000	$ 6,734,000	$ 6,734,000
8 R	1	4.20	4,927.86	$ 153,000	$ 153,000	$ 153,000
8 F	43	305.77	1,725,956.70	$ 16,481,000	$ 16,235,000	$ 16,235,000
10 R	5	21.48	147,366.48	$ 4,576,000	$ 4,576,000	$ 4,576,000
10 F	277	2,352.21	8,218,203.85	$ 107,181,000	$ 96,736,000	$ 96,736,000
Divided R	4	13.54	24,580.64	$ 781,000	$ 781,000	$ 781,000
Divided F	10	61.83	208,166.89	$ 2,920,000	$ 2,643,000	$ 2,643,000
Section Total	826	6,516.88	12,645,907.30	$ 145,126,000	$ 133,825,000	$ 133,825,000
State Total		62,453	174,201,000	$1,291,173,000	$1,236,073,000	$ 1,236,073,000
Number of Bridges on Sections	Number of Bridges on System	Section's Additional Area Sq. Yd.	State's Additional Area Sq. Yd.	Scenario B State Total	Scenario C State Total	Scenario D State Total
3610	20,660	96,400	1,490,600	$ 764,806,000	$ 764,806,000	$ 764,806,000
GRAND TOTAL				$2,055,979,000	$2,000,879,000	$2,000,879,000

R = Rigid Pavement
F = Flexible Pavement

(f) FM with FM routes.

(3) The number of intersections were manually counted (according to the above classes) on the HPMS sections.

(4) The cost figures were obtained by

(a) Using average cost data (Appendix),

(b) New design values as suggested in Chapter 4,

(c) "As built" plans obtained according to (1) and (2) above,

(d) Expanding the sample to allow for the States road network as a whole.

(5) The confidence level of the mean estimator was computed with the use of the t statistic.

(6) The assumption of a normally distributed mean area (additional) to allow for the operation of scenarios C or D was tested with a chi-square goodness of fit test.

To obtain a confidence interval for the mean of a normal distribution when the standard deviation is unknown, the following statistic was used (Ref 5):

The $100(1 - \alpha)\%$ confidence interval is equal to

$$\bar{X} \pm t\alpha/2 \; ; \; n-1 \times \frac{S}{\sqrt{n}}$$

where

$\bar{X}$ = computed mean for the sample,

$\alpha/2$ = probability that the man will be greater or less than the computed mean,

S = standard deviation computed for the sample,

n = number of observations in the sample, and

t = the t statistic.

The chi-square goodness of fit test is used as described by A. H. Bowker and G. J. Lieberman (Ref 5). The chi-square statistic is computed by the following formula:

$$\sum_{i=1}^{k} \frac{(Oi - Ei)}{Ei} \quad \text{for all } i$$

where

O_i = observed frequency and

E_i = theoretical frequency.

The theoretical expected number of observations falling into an interval must be at least 5. To have 2 degrees of freedom, 5 intervals are necessary because estimators are used for the mean and variance. Therefore 25 observations are needed. The 5 intervals all have an expectancy of 0.20. The computed statistic is then tested against the chi-square distribution.

Due to incomplete intersection details (e.g., missing dimensions) on the sampled plans, a large percentage (40 to 50 percent) of the randomly sampled intersections had to be disregarded. Additional plans containing more detailed information were studied, and this may lead to a biased sample. Except for the random sampling, additional samples were treated according to the methodology described above.

For scenario A it is assumed that all intersections are presently designed to allow for operation of all vehicle types without undue encroachment on the adjacent lanes. This is of course not true, particularly for the FM road system. The estimate shown in Table 33 reflects therefore a true picture to upgrade the existing intersections to allow for scenarios C or D, but should the intersections also be designed to allow for scenarios A or B without undue encroachment, a considerable amount of money will be needed. This cost estimate was unfortunately not made.

Interstate Intersecting with an Interstate Highway

There are only two of these intersections on the HPMS sections. To allow for the operation of either scenarios C or D, the following additional areas are required to upgrade the two intersections.

TABLE 33. ADDITIONAL COST ESTIMATE TO UPGRADE INTERSECTIONS

		Average Area (Sq. Yd.)	Number of Intersections on HPMS Sections	Length of HPMS Sections (mi.)	Total Length of System (mi.)	Additional Area for System (Sq. Yd.)	Additional Cost Scenario C	Additional Cost Scenario D
Interstate System	IH	3050.0	2	1157.97	2,214	12,200	$ 700,000	$ 700,000
US and State System	IH US	1824.0 910.0	137 407	4372.93	22,070	3,130,000	$ 68,869,000	$ 68,869,000
FM System	IH US FM	1876.0 574.8 364.4	158 771 157	985.98	38,169	30,845,000	$144,355,000	$144,355,000
Interstate System	IH	3050	2	1157.97	2,214	12,200	$ 700,000	$ 700,000
All Principal Arterials	IH US FM	3050 1824 910	2 122 309	4004.89	10,317.23	1,446,000	$ 29,823,000	$ 29,823,000
"All Systems"			1632	6516.88	62,453	33,987,200	$213,924,000	$213,924,000

Pavement Area (sq yd)	Structural Area (sq yd)
2600	65
3500	400
Average = 3050	Average = 232.5

While only two intersections are involved, no statistical testing can be done, but as these are the only ones on the HPMS sections, the precision level should be the same as that for the HPMS sample.

Interstate Intersecting with a US or State Highway

For the 25 sampled intersections, the additional area (sq yd) required to upgrade the intersections to allow for scenarios C or D are the following:

1250, 1050, 2700, 3200, 2250,
1600, 1800, 2300, 1450, 2000,
1800, 2500, 2750, 2150, 2500,
600, 2200, 1050, 900, 1800,
1200, 2050, 2150, 1300, 1050.

For the above:

$\bar{X}$ = 1824.0

S = 664.91

The 90 percent confidence interval for the above mean is

= 1824.0 + or - 1.711*664.91/SQRT(25)

= (1596.47; 2051.47)

To test the normality hypothesis, the intervals and the number of observations falling into each interval are

Interval	Number of Observations
0-1264	5
1264-1656	4
1656-1992	3
1992-2384	8
2384-inf.	5

From the above the chi-square statistic is

$$\left((5-5)^2 + (5-4)^2 + (5-3)^2 + (5-8)^2 + (5-5)^2 \right) / 5 = 2.80$$

For a 5 percent level of significance, the table value of the chi-square distribution corresponding to 2 degrees of freedom, is 5.991, and the hypothesis that the additional areas are normally distributed is accepted.

Interstate Intersecting with a FM Road

For the 25 sampled intersections, the additional area (sq yd) required to upgrade the intersections to allow for scenarios C or D are the following:

1550, 1400, 2400, 2250, 2500,
500, 450, 1800, 950, 900,
4650, 2050, 1800, 1100, 2200,
1800, 2400, 2500, 1700, 3200,
1250, 1050, 2750, 1350, 2400.

For the above:

$\bar{X}$ = 1876.0

S = 916.53

The 90 percent confidence interval for the above mean is

= 1876.0 + or - 1.711*916.53/SQRT(25)

= (1562.36; 2189.64)

To test the normality hypothesis, the intervals and the number of observations falling into each interval are

Interval	Number of Observations
0-1104	6
1104-1644	4
1644-2108	5
2108-2648	7
2648-inf.	3

From this the chi-square statistic is

$$[(5-6)^2 + (5-4)^2 + (5-5)^2 + (5-7)^2 + (5-3)^2] / 5 = 2.0$$

For a 5 percent level of significance, the table value of the chi-square distribution corresponding to 2 degrees of freedom, is 5.991, and the hypothesis that the additional areas are normally distributed is accepted.

US or State Intersecting with a US or State Road

For the 25 sampled intersections, the additional area (sq yd) required to upgrade the intersections to allow for scenarios C or D are the following:

110, 450, 900, 1300, 920,
150, 800, 800, 600, 300,
1400, 1300, 950, 1800, 700,
1400, 800, 1050, 900, 1200.

From the above:

$\overline{X}$ = 910.0

S = 441.23

The 90 percent confidence interval for the above mean is

= 910.0 + or - 1.711*441.23/SQRT(25)

= (759.01; 1060.99)

To test the normality hypothesis, the intervals and the number of observations falling into each interval are

Interval	Number of Observations
0- 540	5
540- 800	6
801-1025	5
1026-1280	2
1281-inf.	7

From this the chi-square statistic is

$$((5-5)^2 + (5-6)^2 + (5-5)^2 + (5-2)^2 + (5-7)^2) / 5 = 2.80$$

For a 10 percent level of significance, the table value of the chi-square distribution corresponding to 2 degrees of freedom, is 4.605, and the hypothesis that the additional areas are normally distributed is accepted.

US or State Intersecting with an FM Road

For the 25 sampled intersections, the additional areas (sq yd) required to upgrade the intersections to allow for scenarios C and D are the following:

1900,	500,	650,	250,	450,
720,	360,	650,	500,	480,
360,	300,	1100,	200,	800,
200,	450,	650,	250,	1300,
450,	700,	450,	250,	450.

From the above

$\bar{X}$ = 574.80

S = 383.28

The 90 percent confidence interval for the above mean is

= 574.8 + or - 1.711*338.28/SQRT(25)

= (459.04; 690.56).

To test the normality hypothesis, the intervals and the number of observations falling into each interval are

Interval	Number of Observations
0- 252	5
252- 478	8
478- 672	6
672- 897	3
897-inf.	3

From this the chi-square statistic is

$$[(5-5)^2 + (5-8)^2 + (5-6)^2 + (5-3)^2 + (5-3)^2] / 5 = 3.60$$

For a 10 percent level of significance, the table value of the chi-square distribution corresponding to 2 degrees of freedom, is 4.605, and the hypothesis that the additional areas are normally distributed is accepted.

FM Intersecting with a FM Road

For the 25 sampled intersections, the additional areas (sq yd) required to upgrade the intersections to allow for scenarios C or D are the following:

450, 450, 450, 260, 180,
450, 260, 150, 180, 450,
350, 300, 590, 200, 300,
450, 450, 250, 500, 590,
320, 450, 180, 500, 390.

For the above

$\bar{X}$ = 364.40

S = 132.10

The 90 percent confidence interval for the above mean is

= 364.40 + or - 1.318*132.1/SQRT(25)

= (329.58; 399.22)

To test the normality hypothesis, the intervals and the number of observations falling into each interval are

Interval	Number of Observations
0- 253	6
254- 331	5
332- 398	2
399- 476	8
476-inf.	4

From this the chi-square statistic is

$$[(5-6)^2 + (5-5)^2 + (5-2)^2 + (5-8)^2 + (5-4)^2] / 5 = 4.0$$

For a 10 percent level of significance, the table value of the chi-square distribution corresponding to 2 degrees of freedom, is 4.605, and the hypothesis that the additional areas are normally distributed is accepted.

CHAPTER 6. SUMMARY

Assuming that either one of scenarios B, C, or D is implemented, and the reasoning and assumptions made to establish the effect of these scenarios on the design elements, cross section elements, and intersection design elements are reasonable, then the following changes regarding these elements can be expected:

(1) Stopping sight distance

No change from the current policy is foreseen due to the ability of the 2-S1-2-2 and 3-S2-4 combinations to stop within the AASHTO braking distances.

(2) Passing sight distance

Although the implementation of any one of scenarios B, C, or D will require additional sight distance, the current pavement marking policy remains unaffected and no upgrading costs are required.

This element is only applicable to two-lane, two-way operations, and if the current pavement marking practice is maintained, an adverse effect on safety can be expected. This will be due to increased abortive passing maneuvers. To overcome this problem for two-lane rural roads, several recommendations have been made in the past (Ref 15), and some of them are:

(a) That the 2-S1-2-2 and 3-S2-4 combinations only be allowed on divided highways.

(b) That the 2-S1-2-2 and the 3-S2-4 combinations not be allowed on any two-lane rural road with the exception of terminal connectors, unless a careful route evaluation is first made. Matters to be considered are composition of traffic, road alignment and grade, and pavement width. If these combinations are allowed, a large sign indicating the truck length should be mounted on the rear trailer.

(c) That the 2-S1-2-2 and the 3-S2-4 combinations be allowed to operate 24 hours a day including weekends and holidays on divided highways.

(d) That consideration be given to increase the minimum horsepower ratio for them to be at least 350:1, to ensure that a higher minimum speed be maintained.

(3) Pavement widening on curves

Due to the increased offtracking characteristics of the 3-S2-4, additional pavement width will be needed if scenarios C or D is implemented. To upgrade the different road classes will involve pavement widening and estimates as shown in Tables 34 to 36.

(4) Critical lengths of grades

While the performance of today's trucks is superior to that of the AASHTO national representative truck, no adverse effect on the climbing ability of trucks is expected should either one of scenarios B, C, or D be implemented. This statement will be even more valid if, as suggested above, the minimum horsepower ratio for the 3-S2-4, 2-S1-2-2, and 3-S2 is at least 350:1.

(5) Rest areas

While the standard layout of safety rest areas utilizes parallel parking, scenarios B, C, or D will decrease the capacity of the rest areas if either is implemented. Should parallel parking prove impractical for the 3-S2-4 or 2-S1-2-2 vehicles, due to difficult back-up operation, pull-in angle parking might be provided at additional cost.

(6) Lane width

Although no change in the SDHPT policy is expected, a 6-inch increase in vehicle width will necessitate that the current desirable standards be strictly adhered to. This will have a pronounced cost effect for either scenarios B, C, or D. Cost estimates are shown in Tables 34 to 36 to allow for the upgrading of the different road classes, should one of the scenarios be implemented. While this is the existing policy being strictly adhered to, the cost estimates should not be considered as over and above that for scenario A because the same costs will be necessary if the State's road network is upgraded to the current policy.

TABLE 34. SUMMARY OF ADDITIONAL COST TO ALLOW FOR THE IMPLEMENTATION OF SCENARIO B (IN THOUSANDS OF DOLLARS)

Item	Interstate Highways	U.S. and State Highways	Farm-to-Market Highways	Interstate Highways	All Principal Arterials	"All Systems"
To Widen Restricted Curves	0	0	0	0	0	0
To Widen Lane Width To 12 Feet	77	142,042	437,791	77	26,880	579,910
To Widen Shoulders To Desirable Width	684	681,631	608,858	684	226,092	1,291,173
To Widen Bridges To 12 Feet Lane Width	43	41,526	183,255	43	10,422	224,824
To Widen Bridges to Desirable Shoulder Width	135	203,013	561,658	135	65,745	764,806
To Upgrade Intersections	0	0	0	0	0	0
Total	939	1,068,212	1,791,562	939	329,139	2,860,713

TABLE 35. SUMMARY OF ADDITIONAL COST TO ALLOW FOR THE IMPLEMENTATION OF SCENARIO C (IN THOUSANDS OF DOLLARS)

Item	Interstate Highways	U.S. and State Highways	Farm-to-Market Highways	Interstate Highways	All Principal Arterials	"All Systems"
To Widen Restricted Curves	297	5,409	28,471	297	1,979	34,177
To Widen Lane Width To 12 Feet	73	128,355	437,791	73	24,309	566,219
To Widen Shoulders To Desirable Width	660	626,555	608,858	660	204,297	1,236,073
To Widen Bridges To 12 Feet Lane Width	43	41,526	183,255	43	10,422	224,824
To Widen Bridges to Desirable Shoulder Width	135	203,013	561,658	135	65,745	764,806
To Upgrade Intersections	700	68,869	144,355	700	29,829	213,924
Total	1,908	1,073,727	1,964,388	1,908	336,581	3,040,023

TABLE 36. SUMMARY OF ADDITIONAL COSTS TO ALLOW FOR THE IMPLEMENTATION OF SCENARIO D (IN THOUSANDS OF DOLLARS)

Item	Interstate Highways	U.S. and State Highways	Farm-to-Market Highways	Interstate Highways	All Principal Arterials	"All Systems"
To Widen Restricted Curves	297	5,409	28,471	297	1,979	34,177
To Widen Lane Width To 12 Feet	73	128,355	437,791	73	24,309	566,219
To Widen Shoulders To Desirable Width	660	626,555	608,858	660	204,297	1,236,073
To Widen Bridges To 12 Feet Lane Width	43	41,526	183,255	43	10,422	224,824
To Widen Bridges to Desirable Shoulder Width	135	203,013	561,658	135	65,745	764,806
To Upgrade Intersections	700	68,869	144,355	700	29,829	213,924
Total	1,908	1,073,727	1,964,388	1,908	336,581	3,040,023

(7) Width of shoulder

Here as for "Lane width," no change in the current SDHPT policy is expected, but a strict adherence to this policy is recommended. This will be very costly for some of the road classes (see Tables 34 to 36). This cost should not be considered as "over and above" that for scenario A for the same reason given in "Lane width" above.

(8) Guardrails

Since guardrails are designed according to passenger car characteristics, no change is expected.

(9) Minimum design for the sharpest turns

Due to the increased offtracking characteristics and decreasing turning ability, especially for the 3-S2-4, additional pavement width will be needed in confined spaces to allow for the implementation of scenarios C or D. While it is assumed that the existing intersections on all the road classes are designed to allow for the operation of scenario A, this is not so, especially for the Farm to Market roads. Estimates of changes required to allow for the operation of scenarios C or D are shown in Tables 34 to 36. Estimates for all five of the intersection design elements are included because of the close relationships.

(10) Width for turning roadways

As for "Minimum design for sharpest turns," additional pavement width will be needed to accommodate the 3-S2-4 vehicle if either one of scenarios C or D is implemented. The combined cost estimates are shown in Tables 34 to 36.

(11) Sight distance for at-grade intersections

Additional sight distance will be needed because of the increase in truck length, and the additional time required to cross an intersection. No cost estimate was made to allow for scenarios C or D due to insufficient information available on the existing sight distances or the restriction on sight distance at intersections.

(12) Median openings

Due to the increased offtracking characteristics of the vehicle combinations in scenarios C and D, additional pavement area will be needed to accommodate the 3-S2-4 and 2-S1-2-2 without undue encroachment on adjacent lanes. Estimates were made to allow for their operation, and the combined costs are shown in Tables 34 to 36.

(13) Median lanes

While both AASHTO and the SDHPT consider only passenger car characteristics when designing median lanes, no cost is involved but the storage capacity of existing median lanes will be reduced if scenarios C or D is implemented. In the future more emphasis should be placed on traffic composition when designing these facilities.

CONCLUSION

(A) Regarding the Efforts of This Report

If any one of scenarios B, C, or D is implemented, some alterations to the State's road network will be necessary. Table 37 shows the total cost needed for the different road classes. From this it can be seen that there is no significant difference in cost to allow for the implementation of either scenarios B, C, or D. This is mainly due to the fact that lane and shoulder widths are currently below the desirable minimum. To add additional pavement for scenario B is also more expensive per square yard than for any one of scenarios C or D. (See Appendix 1.)

While there is so little difference in cost between the implementation of scenarios B, C, or D, considerations other than geometric design should be used to decide on which scenario will best serve the prosperity and vitality of the State.

(B) Regarding the Need for Future Research

The following has been pointed out in Chapters 2 through 4:

(1) That the existing procedure used by AASHTO to calculate the required passing sight distance is only considering the case of a passenger car overtaking a passenger car. In future research the relationship between

TABLE 37. SUMMARY OF ADDITIONAL COSTS TO ALLOW FOR SCENARIO B, C, OR D (IN THOUSANDS OF DOLLARS)

	Case 1			Case 2		
Item	Interstate Highways	U.S. and State Highways	Farm to Market Highways	Interstate Highways	All Principal Arterials	"All Systems"
Scenario B	939	1,068,212	1,791,562	939	329,139	2,860,713
Scenario C	1,908	1,073,727	1,964,388	1,908	336,581	3,040,023
Scenario D	1,908	1,073,727	1,964,388	1,908	336,581	3,040,023

passing sight distance and the passing maneuvers which involve trucks and truck lengths needs more attention because of the serious safety implications.

(2) In future research the performance of trucks on grades (acceleration and deceleration) needs attention because the current AASHTO standards are based on old data.

(3) The question of lane width, safety and vehicle width also needs additional attention in order to arrive at a conclusive answer as to the desirable lane width standards. Lane width can be an expensive item in the construction and maintenance of roads. A move towards a cost benefit design can be accomplished only if additional safety implications are known and a cost is attached to safety versus lane width.

(4) As for lane width, a more conclusive study of shoulder width, safety and vehicle width is needed. This will lead to a cost benefit decision.

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APPENDIX 1

AVERAGE COST DATA

TABLE A1.1. SUMMARY OF NEW PAVEMENT COSTS FOR THE GEOMETRIC PHASE OF THE TEXAS TRUCK STUDY

(INTERSTATE HIGHWAY)

	Pavement Type	Scenarios A	B	C	D
Urban	Flexible	$ 26.84	$ 27.66	$ 25.62	$ 25.62
	Rigid	$ 37.36	$ 37.36	$ 37.36	$ 37.36
Rural	Flexible	$ 25.33	$ 26.51	$ 25.09	$ 25.09
	Rigid	$ 37.08	$ 37.08	$ 37.08	$ 37.08

Notes: (1) All costs are in $/S.Y.

(2) Indicated costs are applicable to mainlanes, shoulders, and paved medians.

(3) Costs are for pavement structures only.

TABLE A1.2. SUMMARY OF NEW PAVEMENT COSTS FOR THE GEOMETRIC PHASE OF THE TEXAS TRUCK STUDY

(OTHER U.S. AND STATE HIGHWAYS)

	Pavement Type	Scenarios			
		A	B	C	D
Urban	Flexible	$ 11.91	$ 13.11	$ 11.91	$ 11.91
	Rigid	$ 31.35	$ 31.35	$ 31.35	$ 31.35
Rural	Flexible	$ 12.10	$ 13.43	$ 12.10	$ 12.10
	Rigid	$ 31.05	$ 31.05	$ 31.05	$ 31.05

Note: (1) All costs are in $/S.Y.

(2) Indicated costs are applicable to mainlanes, shoulders, and paved medians.

(3) Costs are for pavement structures only.

TABLE A1.3. SUMMARY OF NEW PAVEMENT COSTS FOR THE GEOMETRIC PHASE OF THE TEXAS TRUCK STUDY

(FARM-TO-MARKET HIGHWAYS)

	Pavement Type	Scenarios A	B	C	D
Urban	Flexible	$ 4.68	$ 4.68	$ 4.68	$ 4.68
	Rigid	NA	NA	NA	NA
Rural	Flexible	$ 4.68	$ 4.68	$ 4.68	$ 4.68
	Rigid	NA	NA	NA	NA

Notes: (1) All costs are in $/S.Y.

(2) Indicated costs are applicable to mainlanes, shoulders, and paved medians.

(3) Rigid pavements are not considered as a replacement for FM highways.

(4) Costs are for pavement structures only.

APPENDIX 2

COMPUTER PROGRAMS, INDEX TO THE HPMS DATA, AND ROAD STATISTICS

```
C PROGRAM 1
C FOR INTERSTATE HIGHWAYS
C
C TO CALCULATE ADDITIONAL PAVEMENT TO WIDEN LANES TO 12 FEET
C I=URBAN/RURAL CODE, N=HIGHWAY CODE, K=#OF LANES
C M=LANE WIDTH, K1=SURFACE TYPE, L=SECTION LENGTH*100
C XLEN=TOT. LENGTH ALL SECTIONS
C NO=NUMBER OF BRIDGES ON SECTION
C BNB=TOTAL BRIDGES FOR ALL SECTIONS
C B9=EXTRA BRIDGE WIDTH REQUIRED TO WIDEN TO 12 FT
C B10,B11=AS ABOVE FOR 10FT AND 11FT LANES
C XL9F,R=TOT.LENGTH 9 FEET SECTIONS (R=RIGID,F=FEXIBLE)
C XL10F,R=AS ABOVE FOR 10 FEET SECTIONS
C XL11F,R=AS ABOVF
C XL12=TOT LENGTH ALL SECTIONS WIDTH>12 FEET
C NUM= TOT. # SECTIONS,N9= # SEC. .LE. 9 FEET
C N10=# .EQ. 10 FFET,N11=#.EQ. 11 FEET,12=#.EQ.12 FEET
C AREAR/F=EXTRA SQ. YD.(TOTAL) WITH R AND F AS ABOVE
C AR9R,F=EXTRA FOR 9 FEET PAVEMENTS,AR10R,F=FOR 10 FEET
C AR11R,F=FOR 11FEET
C
C
      PROGRAM MAIN (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE7)
      NUM=N9R=N9F=N10R=N10F=N11R=N11F=N12=0
      XLEN=XL9R=XL9F=XL10R=XL10F=XL11R=XL11F=XL12=0
      AREA=AR9R=AR9F=AR10R=AR10F=AR11R=AR11F=0
      I1=I2=I3=I4=0
      IN1=IN2=IN3=IN4=ITOT=0
      B9=B10=B11=B12=BA=BNB=0
      WRITE(6,10)
 10   FORMAT(1H1,5X,≠LANE WIDTH≠,5X,≠NO.OF SEC.≠,
     25X,≠LENGTH MI.≠,10X,≠ADD. AREA≠,5X,≠COST≠//)
 20   READ(5,30,END=120)I,N,L,K,M,K1,I1,I2,I3,I4,NO
 30   FORMAT(I1,24X,I2,4X,I4,5X,I2,I2,12X,I2,7X,I2,I2,I2,I2,47X,I2)
      IF (I.EQ.2) GO TO 40
      GO TO 20
 40   IF(N.EQ.1) GO TO 50
      GO TO 20
 50   XLEN = XLEN + L/100.
      NUM = NUM + 1
      BNB=BNB + NO
      IN1=IN1 +I1
      IN2=IN2 +I2
      IN3=IN3 +I3
      IN4=IN4 +I4
      IF(M.LT.12) GO TO 60
      N12 = N12 + 1
      XL12 = XL12 + L/100.
      GO TO 20
```

```
60    IF (M.GT.9) GO TO 80
      IF (K1.LE.60) GO TO 70
      AR9R = AR9R + K*(12.-M)*L*5.86666
      N9R = N9R + 1
      XL9R = XL9R + L/100.
      B9=B9 + NO*K
      GO TO 20
70    AR9F = AR9F +K*(12.-M)*L*5.8666
      N9F = N9F + 1
      XL9F = XL9F + L/100.
      B9=B9 + NO*K
       GO TO 20



80    IF (M .GT. 10) GO TO 100
      IF (K1.LE.60) GO TO 90
      AR10R = AR10R + K*(12.-M)*L*5.86666
      N10R = N10R +1
      XL10R =XL10R + L/100.
      B10=B10 + NO*K
      GO TO 20
90    AR10F = AR10F + K*(12.-M)*L*5.8666
      N10F=N10F + 1
      XL10F = XL10F + L/100.
      B10=B10 + NO*K
      GO TO 20
100   IF(K1.LE.60) GO TO 110
      AR11R =AR11R +K*(12.-M)*L*5.8666
      N11R=N11R + 1
      XL11R =XL11R + L/100.
      B11=B11 + NO*K
      GO TO 20
110   AR11F=AR11F + K*(12.-M)*L*5.8666
      N11F=N11F + 1
      XL11F=XL11F + L/100.
      B11=B11 + NO*K
      GO TO 20
120   AREA = AR9R + AR9F +AR10R +AR10F +AR11R +AR11F
      ITOT=IN1+IN2+IN3+IN4
      BA=B9 + B10 + B11
      C1 = ≠9 FT RIGID≠
      C2 = ≠9 FT FLEX≠
      C3 = ≠10   RIGID≠
      C4 = ≠10   FLEX≠
      C5 = ≠11   RIGID≠
      C6 = ≠11   FLEX≠
      C7 = ≠12 FT PAV≠
      C8 = ≠TOTAL≠
      WRITE(6,130)C1,N9R,XL9R,AR9R
130   FORMAT(5X,A10,I15,F15.2,F16.2)
```

```
      WRITE(6,130)C2,N9F,XL9F,AR9F
      WRITE(6,130)C3,N10R,XL10R,AR10R
      WRITE(6,130)C4,N10F,XL10F,AR10F
      WRITE(6,130)C5,N11R,XL11R,AR11R
      WRITE(6,130)C6,N11F,XL11F,AR11F
      WRITE(6,130)C7,N12,XL12,
      WRITE(6,140)C8,NUM,XLEN,AREA
140   FORMAT(5X,A10,I15,F15.2,F16.2//)
      WRITE(6,150)
150   FORMAT(5X,≠INTECHANGE≠,5X,≠GRADE SIG.≠,5X,
     2≠GRADE STOP≠,5X,≠UNSIGNAL≠,5X,≠TOTAL≠//)
      WRITE(6,160)IN1,IN2,IN3,IN4,ITOT
160   FORMAT(5X,I5,10X,I5,10X,I5,10X,I5,8X,I5)
      WRITE(6,170)
170   FORMAT(5X,≠NO BRIDGES≠,5X,≠9 FT. AREA≠,5X,≠10FT AREA≠
     2,6X,≠11 FT AREA≠,5X,≠TOTAL AREA≠//)
      WRITE(6,180)BNB,B9,B10,B11,BA
180   FORMAT(5X,F10.0,5X,F10.2,5X,F10.2,
     25X,F10.2,5X,F10.2)
      STOP
      END
```

```
C PROGRAM 2
C FOR PRINCIPAL ARTERIALS EXCLUDING INTERSTATE
C
C TO CALCULATE ADDITIONAL PAVEMENT TO WIDEN LANES TO 12 FEET
C I=URBAN/RURAL CODE, N=HIGHWAY CODE, K=# OF LANES
C M=LANE WIDTH, K1=SURFACE TYPE, L=SECTION LENGTH*100
C XLEN=TOT. LENGTH ALL SECTIONS
C NO=NUMBER OF BRIDGES ON SECTION
C BNB=TOTAL BRIDGES FOR ALL SECTIONS
C B9=EXTRA BRIDGE WIDTH REQUIRED TO WIDEN TO 12 FT
C B10,B11=AS ABOVE FOR 10FT AND 11FT LANES
C XL9F,R=TOT.LENGTH 9 FEET SECTIONS (R=RIGID,F=FEXIBLE)
C XL10F,R=AS ABOVE FOR 10 FEET SECTIONS
C XL11F,R=AS ABOVE
C XL12=TOT LENGTH ALL SECTIONS WIDTH>12 FEET
C NUM= TOT. # SECTIONS,N9= # SEC. .LE. 9 FEET
C N10=# .EQ. 10 FEET,N11=#.EQ. 11 FEET,12=#.EQ.12 FEET
C AREAR/F=EXTRA SQ. YD.(TOTAL) WITH R AND F AS ABOVE
C AR9R,F=EXTRA FOR 9 FEET PAVEMENTS,AR10R,F=FOR 10 FEET
C AR11R,F=FOR 11FEET
C
C
      PROGRAM MAIN (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE7)
      NUM=N9R=N9F=N10R=N10F=N11R=N11F=N12=0
      XLEN=XL9R=XL9F=XL10R=XL10F=XL11R=XL11F=XL12=0
      AREA=AR9R=AR9F=AR10R=AR10F=AR11R=AR11F=0
      I1=I2=I3=I4=0
      IN1=IN2=IN3=IN4=ITOT=0
      B9=B10=B11=B12=BA=BNB=0
      WRITE(6,10)
 10   FORMAT(1H1,5X,*LANE WIDTH*,5X,*NO.OF SEC.*,
     25X,*LENGTH MI.*,10X,*ADD. AREA*,5X,*COST*//)
 20   READ(5,30,END=120)I,N,L,K,M,K1,I1,I2,I3,I4,NO
 30   FORMAT(I1,24X,I2,4X,I4,5X,I2,I2,12X,I2,7X,I2,I2,I2,I2,47X,I2)
      IF (I.EQ.2) GO TO 40
      GO TO 20
 40   IF(N.EQ.2) GO TO 50
      GO TO 20
 50   XLEN = XLEN + L/100.
      NUM = NUM + 1
      BNB=BNB + NO
      IN1=IN1 +I1
      IN2=IN2 +I2
      IN3=IN3 +I3
      IN4=IN4 +I4
      IF(M.LT.12) GO TO 60
      N12 = N12 + 1
      XL12 = XL12 + L/100.
      GO TO 20
```

```
60    IF (M.GT.9) GO TO 80
      IF (K1.LE.60) GO TO 70
      AR9R = AR9R + K*(12.-M)*L*5.86666
      N9R = N9R + 1
      XL9R = XL9R + L/100.
      B9=B9 + NO*K
      GO TO 20
70    AR9F = AR9F +K*(12.-M)*L*5.8666
      N9F = N9F + 1
      XL9F = XL9F + L/100.
      B9=B9 + NO*K
       GO TO 20



80    IF (M .GT. 10) GO TO 100
      IF (K1.LE.60) GO TO 90
      AR10R = AR10R + K*(12.-M)*L*5.86666
      N10R = N10R +1
      XL10R =XL10R + L/100.
      B10=B10 + NO*K
      GO TO 20
90    AR10F = AR10F + K*(12.-M)*L*5.8666
      N10F=N10F + 1
      XL10F = XL10F + L/100.
      B10=B10 + NO*K
      GO TO 20
100   IF(K1.LE.60) GO TO 110
      AR11R =AR11R +K*(12.-M)*L*5.8666
      N11R=N11R + 1
      XL11R =XL11R + L/100.
      B11=B11 + NO*K
      GO TO 20
110   AR11F=AR11F + K*(12.-M)*L*5.8666
      N11F=N11F + 1
      XL11F=XL11F + L/100.
      B11=B11 + NO*K
      GO TO 20
120   AREA = AR9R + AR9F +AR10R +AR10F +AR11R +AR11F
      ITOT=IN1+IN2+IN3+IN4
      BA=B9 + B10 + B11
      C1 = ≠9 FT RIGID≠
      C2 = ≠9 FT FLEX≠
      C3 = ≠10   RIGID≠
      C4 = ≠10   FLEX≠
      C5 = ≠11   RIGID≠
      C6 = ≠11   FLEX≠
      C7 = ≠12 FT PAV≠
      C8 = ≠TOTAL≠
      WRITE(6,130)C1,N9R,XL9R,AR9R
130   FORMAT(5X,A10,I15,F15.2,F16.2)
```

```
      WRITE(6,130)C2,N9F,XL9F,AR9F
      WRITE(6,130)C3,N10R,XL10R,AR10R
      WRITE(6,130)C4,N10F,XL10F,AR10F
      WRITE(6,130)C5,N11R,XL11R,AR11R
      WRITE(6,130)C6,N11F,XL11F,AR11F
      WRITE(6,130)C7,N12,XL12,
      WRITE(6,140)C8,NUM,XLEN,AREA
140   FORMAT(5X,A10,I15,F15.2,F16.2//)
      WRITE(6,150)
150   FORMAT(5X,≠INTECHANGE≠,5X,≠GRADE SIG.≠,5X,
     2≠GRADE STOP≠,5X,≠UNSIGNAL≠,5X,≠TOTAL≠//)
      WRITE(6,160)IN1,IN2,IN3,IN4,ITOT
160   FORMAT(5X,I5,10X,I5,10X,I5,10X,I5,8X,I5)
      WRITE(6,170)
170   FORMAT(5X,≠NO BRIDGES≠,5X,≠9 FT. AREA≠,5X,≠10FT AREA≠
     2,6X,≠11 FT AREA≠,5X,≠TOTAL AREA≠//)
      WRITE(6,180)BNB,B9,B10,B11,BA
180   FORMAT(5X,F10.0,5X,F10.2,5X,F10.2,
     25X,F10.2,5X,F10.2)
      STOP
      END
```

```
C PROGRAM 3
C ALL SYSTEMS
C
C TO CALCULATE ADDITIONAL PAVEMENT TO WIDEN LANES TO 12 FEET
C I=URBAN/RURAL CODE, N=HIGHWAY CODE, K=# OF LANES
C M=LANE WIDTH, K1=SURFACE TYPE, L=SECTION LENGTH*100
C XLEN=TOT. LENGTH ALL SECTIONS
C NO=NUMBER OF BRIDGES ON SECTION
C BNB=TOTAL BRIDGES FOR ALL SECTIONS
C B9=EXTRA BRIDGE WIDTH REQUIRED TO WIDEN TO 12 FT
C B10,B11=AS ABOVE FOR 10FT AND 11FT LANES
C XL9F,R=TOT.LENGTH 9 FEET SECTIONS (R=RIGID,F=FEXIBLE)
C XL10F,R=AS ABOVE FOR 10 FEET SECTIONS
C XL11F,R=AS ABOVE
C XL12=TOT LENGTH ALL SECTIONS WIDTH>12 FEET
C NUM= TOT. # SECTIONS,N9= # SEC. .LE. 9 FEET
C N10=# .EQ. 10 FEET,N11=#.EQ. 11 FEET,12=#.EQ.12 FEET
C AREAR/F=EXTRA SQ. YD.(TOTAL) WITH R AND F AS ABOVE
C AR9R,F=EXTRA FOR 9 FEET PAVEMENTS,AR10R,F=FOR 10 FEET
C AR11R,F=FOR 11FEET
C
C
      PROGRAM MAIN (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE7)
      NUM=N9R=N9F=N10R=N10F=N11R=N11F=N12=0
      XLEN=XL9R=XL9F=XL10R=XL10F=XL11R=XL11F=XL12=0
      AREA=AR9R=AR9F=AR10R=AR10F=AR11R=AR11F=0
      I1=I2=I3=I4=0
      IN1=IN2=IN3=IN4=ITOT=0
      B9=B10=B11=B12=BA=BNB=0
      WRITE(6,10)
 10   FORMAT(1H1,5X,*LANE WIDTH*,5X,*NO.OF SEC.*,
     25X,*LENGTH MI.*,10X,*ADD. AREA*,5X,*COST*//)
 20   READ(5,30,END=120)I,N,L,K,M,K1,I1,I2,I3,I4,NO
 30   FORMAT(I1,24X,I2,4X,I4,5X,I2,I2,12X,I2,7X,I2,I2,I2,I2,47X,I2)
      IF (I.EQ.2) GO TO 40
      GO TO 20
 40   IF(N.LE.8) GO TO 50
      GO TO 20
 50   XLEN = XLEN + L/100.
      NUM = NUM + 1
      BNB=BNB + NO
      IN1=IN1 +I1
      IN2=IN2 +I2
      IN3=IN3 +I3
      IN4=IN4 +I4
      IF(M.LT.12) GO TO 60
      N12 = N12 + 1
      XL12 = XL12 + L/100.
      GO TO 20
 60   IF (M.GT.9) GO TO 80
```

```
      IF (K1.LE.60) GO TO 70
      AR9R = AR9R + K*(12.-M)*L*5.86666
      N9R = N9R + 1
      XL9R = XL9R + L/100.
      B9=B9 + NO*K
      GO TO 20
70    AR9F = AR9F +K*(12.-M)*L*5.8666
      N9F = N9F + 1
      XL9F = XL9F + L/100.
      B9=B9 + NO*K
       GO TO 20




80    IF (M .GT. 10) GO TO 100
      IF (K1.LE.60) GO TO 90
      AR10R = AR10R + K*(12.-M)*L*5.86666
      N10R = N10R +1
      XL10R =XL10R + L/100.
      B10=B10 + NO*K
      GO TO 20
90    AR10F = AR10F + K*(12.-M)*L*5.8666
      N10F=N10F + 1
      XL10F = XL10F + L/100.
      B10=B10 + NO*K
      GO TO 20
100   IF(K1.LE.60) GO TO 110
      AR11R =AR11R +K*(12.-M)*L*5.8666
      N11R=N11R + 1
      XL11R =XL11R + L/100.
      B11=B11 + NO*K
      GO TO 20
110   AR11F=AR11F + K*(12.-M)*L*5.8666
      N11F=N11F + 1
      XL11F=XL11F + L/100.
      B11=B11 + NO*K
      GO TO 20
120   AREA = AR9R + AR9F +AR10R +AR10F +AR11R +AR11F
      ITOT=IN1+IN2+IN3+IN4
      BA=B9 + B10 + B11
      C1 = ≠9 FT RIGID≠
      C2 = ≠9 FT FLEX≠
      C3 = ≠10   RIGID≠
      C4 = ≠10   FLEX≠
      C5 = ≠11   RIGID≠
      C6 = ≠11   FLEX≠
      C7 = ≠12 FT PAV≠
      C8 = ≠TOTAL≠
      WRITE(6,130)C1,N9R,XL9R,AR9R
130   FORMAT(5X,A10,I15,F15.2,F16.2)
      WRITE(6,130)C2,N9F,XL9F,AR9F
```

```
      WRITE(6,130)C3,N10R,XL10R,AR10R
      WRITE(6,130)C4,N10F,XL10F,AR10F
      WRITE(6,130)C5,N11R,XL11R,AR11R
      WRITE(6,130)C6,N11F,XL11F,AR11F
      WRITE(6,130)C7,N12,XL12,
      WRITE(6,140)C8,NUM,XLEN,AREA
140   FORMAT(5X,A10,I15,F15.2,F16.2//)
      WRITE(6,150)
150   FORMAT(5X,≠INTECHANGE≠,5X,≠GRADE SIG.≠,5X,
     2≠GRADE STOP≠,5X,≠UNSIGNAL≠,5X,≠TOTAL≠//)
      WRITE(6,160)IN1,IN2,IN3,IN4,ITOT
160   FORMAT(5X,I5,10X,I5,10X,I5,10X,I5,8X,I5)
      WRITE(6,170)
170   FORMAT(5X,≠NO BRIDGES≠,5X,≠9 FT. AREA≠,5X,≠10FT AREA≠
     2,6X,≠11 FT AREA≠,5X,≠TOTAL AREA≠//)
      WRITE(6,180)BN8,B9,B10,B11,BA
180   FORMAT(5X,F10.0,5X,F10.2,5X,F10.2,
     25X,F10.2,5X,F10.2)
      STOP
      END
```

```
C PROGRAM 4
C COUNTY ROADS
C
C TO CALCULATE ADDITIONAL PAVEMENT TO WIDEN LANES TO 12 FEET
C I=URBAN/RURAL CODE, N=HIGHWAY CODE, K=# OF LANES
C M=LANE WIDTH, K1=SURFACE TYPE, L=SECTION LENGTH*100
C XLEN=TOT. LENGTH ALL SECTIONS
C NO=NUMBER OF BRIDGES ON SECTION
C BNB=TOTAL BRIDGES FOR ALL SECTIONS
C B9=EXTRA BRIDGE WIDTH REQUIRED TO WIDEN TO 12 FT
C B10,B11=AS ABOVE FOR 10FT AND 11FT LANES
C XL9F,R=TOT.LENGTH 9 FEET SECTIONS (R=RIGID,F=FEXIBLE)
C XL10F,R=AS ABOVE FOR 10 FEET SECTIONS
C XL11F,R=AS ABOVE
C XL12=TOT LENGTH ALL SECTIONS WIDTH>12 FEET
C NUM= TOT. # SECTIONS,N9= # SEC. .I.E. 9 FEET
C N10=# .EQ. 10 FEET,N11=#.EQ. 11 FEET,12=#.EQ.12 FEET
C AREAR/F=EXTRA SQ. YD.(TOTAL) WITH R AND F AS ABOVE
C AR9R,F=EXTRA FOR 9 FEET PAVEMENTS.AR10R,F=FOR 10 FEET
C AR11R,F=FOR 11FFET
C N1= JURISDICTIONAL RESPONSIBILITY
C
C
      PROGRAM MAIN (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE7)
      NUM=N9R=N9F=N10R=N10F=N11R=N11F=N12=0
      XLEN=XL9R=XL9F=XL10R=XL10F=XL11R=XL11F=XL12=0
      AREA=AR9R=AR9F=AR10R=AR10F=AR11R=AR11F=0
      I1=I2=I3=I4=0
      IN1=IN2=IN3=IN4=ITOT=0
      B9=B10=B11=B12=BA=BNB=0
      WRITE(6,10)
 10   FORMAT(1H1,5X,=LANE WIDTH=,5X,=NO.OF SEC.=,
     25X,=LENGTH MI.=,10X,=ADD. AREA=,5X,=COST=//)
 20   READ(5,30,END=120)I,N,N1,L,K,M,K1,I1,I2,I3,I4,NO
 30   FORMAT(I1,24X,I2,3X,I1,I4,5X,I2,I2,12X,I2,7X,I2,I2,I2,I2,47X,I2)
      IF (I.EQ.2) GO TO 40
      GO TO 20
 40   IF(N.LE.8) GO TO 50
      GO TO 20
 50   IF(N1.GT.2) GO TO 55
      GO TO 20
 55   XLEN=XLEN + L/100.
      NUM = NUM + 1
      BNB=BNB + NO
      IN1=IN1 +I1
      IN2=IN2 +I2
      IN3=IN3 +I3
      IN4=IN4 +I4
      IF(M.LT.12) GO TO 60
      N12 = N12 + 1
```

```
      XL12 = XL12 + L/100.
      GO TO 20
60    IF (M.GT.9) GO TO 80
      IF (K1.LE.60) GO TO 70
      AR9R = AR9R + K*(12.-M)*L*5.86666
      N9R = N9R + 1
      XL9R = XL9R + L/100.
      B9=B9 + NO*K
      GO TO 20
70    AR9F = AR9F +K*(12.-M)*L*5.8666
      N9F = N9F + 1
      XL9F = XL9F + L/100.
      B9=B9 + NO*K
       GO TO 20
80    IF (M .GT. 10) GO TO 100
      IF (K1.LE.60) GO TO 90
      AR10R = AR10R + K*(12.-M)*L*5.86666
      N10R = N10R +1
      XL10R =XL10R + L/100.
      B10=B10 + NO*K
      GO TO 20
90    AR10F = AR10F + K*(12.-M)*L*5.8666
      N10F=N10F + 1
      XL10F = XL10F + L/100.
      B10=B10 + NO*K
      GO TO 20
100   IF(K1.LE.60) GO TO 110
      AR11R =AR11R +K*(12.-M)*L*5.8666
      N11R=N11R + 1
      XL11R =XL11R + L/100.
      B11=B11 + NO*K
      GO TO 20
110   AR11F=AR11F + K*(12.-M)*L*5.8666
      N11F=N11F + 1
      XL11F=XL11F + L/100.
      B11=B11 + NO*K
      GO TO 20
120   AREA = AR9R + AR9F +AR10R +AR10F +AR11R +AR11F
      ITOT=IN1+IN2+IN3+IN4
      BA=B9 + B10 + B11
      C1 = ≠9 FT RIGID≠
      C2 = ≠9 FT FLEX≠
      C3 = ≠10   RIGID≠
      C4 = ≠10   FLEX≠
      C5 = ≠11   RIGID≠
      C6 = ≠11   FLEX≠
      C7 = ≠12 FT PAV≠
      C8 = ≠TOTAL≠
      WRITE(6,130)C1,N9R,XL9R,AR9R
```

```
130  FORMAT(5X,A10,I15,F15.2,F16.2)
     WRITE(6,130)C2,N9F,XL9F,AR9F
     WRITE(6,130)C3,N10R,XL10R,AR10R
     WRITE(6,130)C4,N10F,XL10F,AR10F
     WRITE(6,130)C5,N11R,XL11R,AR11R
     WRITE(6,130)C6,N11F,XL11F,AR11F
     WRITE(6,130)C7,N12,XL12,
     WRITE(6,140)C8,NUM,XLFN,AREA
140  FORMAT(5X,A10,I15,F15.2,F16.2//)
     WRITE(6,150)
150  FORMAT(5X,*INTECHANGE*,5X,*GRADE SIG.*,5X,
    2*GRADE STOP*,5X,*UNSIGNAL*,5X,*TOTAL*//)
     WRITE(6,160)IN1,IN2,IN3,IN4,ITOT
160  FORMAT(5X,I5,10X,I5,10X,I5,10X,I5,8X,I5)
     WRITE(6,170)
170  FORMAT(5X,*NO BRIDGES*,5X,*9 FT. AREA*,5X,*10FT AREA*
    2,6X,*11 FT AREA*,5X,*TOTAL AREA*//)
     WRITE(6,180)BNB,B9,B10,B11,BA
180  FORMAT(5X,F10.0,5X,F10.2,5X,F10.2,
    25X,F10.2,5X,F10.2)
     STOP
     END
```

```
C PROGRAM 5
C FARM TO MARKET
C
C TO CALCULATE ADDITIONAL PAVEMENT TO WIDEN LANES TO 12 FEET
C I=URBAN/RURAL CODE, N=HIGHWAY CODE, K=# OF LANES
C M=LANE WIDTH, K1=SURFACE TYPE, L=SECTION LENGTH*100
C XLEN=TOT. LENGTH ALL SECTIONS
C NO=NUMBER OF BRIDGES ON SECTION
C BNB=TOTAL BRIDGES FOR ALL SECTIONS
C B9=EXTRA BRIDGE WIDTH REQUIRED TO WIDEN TO 12 FT
C B10,B11=AS ABOVE FOR 10FT AND 11FT LANES
C XL9F,R=TOT.LENGTH 9 FEET SECTIONS (R=RIGID,F=FEXIBLE)
C XL10F,R=AS ABOVE FOR 10 FEET SECTIONS
C XL11F,R=AS ABOVE
C XL12=TOT LENGTH ALL SECTIONS WIDTH>12 FEET
C NUM= TOT. # SECTIONS,N9= # SEC. .LE. 9 FEET
C N10=# .EQ. 10 FEET,N11=#.EQ. 11 FEET,12=#.EQ.12 FEET
C AREAR/F=EXTRA SQ. YD.(TOTAL) WITH R AND F AS ABOVE
C AR9R,F=EXTRA FOR 9 FEET PAVEMENTS,AR10R,F=FOR 10 FEET
C AR11R,F=FOR 11FEET
C
C
      PROGRAM MAIN(INPUT1,INPUT2,OUTPUT,TAPE5=INPUT1,TAPE4=INPUT2
     2,TAPE6=OUTPUT,TAPE7)
      NUM=N9R=N9F=N10R=N10F=N11R=N11F=N12=0
      XLEN=XL9R=XL9F=XL10R=XL10F=XL11R=XL11F=XL12=0
      AREA=AR9R=AR9F=AR10R=AR10F=AR11R=AR11F=0
      I1=I2=I3=I4=0
      IN1=IN2=IN3=IN4=ITOT=0
      B9=B10=B11=BA=BNB=0
      WRITE(6,10)
 10   FORMAT(1H1,5X,*LANE WIDTH*,5X,*NO.OF SEC.*,
     25X,*LENGTH MI.*,10X,*ADD. AREA*,5X,*COST*//)
 20   READ(5,30,END=120)I,IX,X3,D,N,L,K,M,K1,I1,I2,I3,I4,NO
 30   FORMAT(T1,5X,I3,A10,A2,4X,I2,4X,I4,5X,I2
     2,I2,12X,I2,7X,I2,I2,I2,I2,47X,I2)
      IF (I.EQ.2) GO TO 40
      GO TO 20
 40   IF(N.GT.2.AND.N.LE.8) GO TO 41
      GO TO 20
 41   READ(4,42,END=50)IX1,X4,X2
 42   FORMAT(I3,A10,A2)
      IF(IX1.EQ.IX) GO TO 43
      GO TO 41
 43   IF(X4.EQ.X3) GO TO 44
      GO TO 41
 44   IF(X2.EQ.D) GO TO 51
      GO TO 41
 50   REWIND 4
      GO TO 20
```

```
51    REWIND 4
      XLEN=XLEN + L/100.
      NUM = NUM + 1
      BNB=BNB + NO
      IN1=IN1 +I1
      IN2=IN2 +I2
      IN3=IN3 +I3
      IN4=IN4 +I4
      IF(M.LT.12) GO TO 60
      N12 = N12 + 1
      XL12 = XL12 + L/100.



      GO TO 20
60    IF (M.GT.9) GO TO 80
      IF (K1.LE.60) GO TO 70
      AR9R = AR9R + K*(12.-M)*L*5.86666
      N9R = N9R + 1
      XL9R = XL9R + L/100.
      B9=B9 + NO*K
      GO TO 20
70    AR9F = AR9F +K*(12.-M)*L*5.8666
      N9F = N9F + 1
      XL9F = XL9F + L/100.
      B9=B9 + NO*K
       GO TO 20
80    IF (M .GT. 10) GO TO 100
      IF (K1.LE.60) GO TO 90
      AR10R = AR10R + K*(12.-M)*L*5.86666
      N10R = N10R +1
      XL10R =XL10R + L/100.
      B10=B10 + NO*K
      GO TO 20
90    AR10F = AR10F + K*(12.-M)*L*5.8666
      N10F=N10F + 1
      XL10F = XL10F + L/100.
      B10=B10 + NO*K
      GO TO 20
100   IF(K1.LE.60) GO TO 110
      AR11R =AR11R +K*(12.-M)*L*5.8666
      N11R=N11R + 1
      XL11R =XL11R + L/100.
      B11=B11 + NO*K
      GO TO 20
110   AR11F=AR11F + K*(12.-M)*L*5.8666
      N11F=N11F + 1
      XL11F=XL11F + L/100.
      B11=B11 + NO*K
      GO TO 20
120   AREA = AR9R + AR9F +AR10R +AR10F +AR11R +AR11F
```

```
      ITOT=IN1+IN2+IN3+IN4
      BA=B9 + B10 + B11
      C1 = ≠9 FT RIGID≠
      C2 = ≠9 FT FLEX≠
      C3 = ≠10   RIGID≠
      C4 = ≠10   FLEX≠
      C5 = ≠11   RIGID≠
      C6 = ≠11   FLEX≠
      C7 = ≠12 FT PAV≠
      C8 = ≠TOTAL≠
      WRITE(6,130)C1,N9R,XL9R,AR9R
130   FORMAT(5X,A10,I15,F15.2,F16.2)
      WRITE(6,130)C2,N9F,XL9F,AR9F
      WRITE(6,130)C3,N10R,XL10R,AR10R
      WRITE(6,130)C4,N10F,XL10F,AR10F
      WRITE(6,130)C5,N11R,XL11R,AR11R
      WRITE(6,130)C6,N11F,XL11F,AR11F
      WRITE(6,130)C7,N12,XL12,
      WRITE(6,140)C8,NUM,XLFN,AREA
140   FORMAT(5X,A10,I15,F15.2,F16.2//)
      WRITE(6,150)
150   FORMAT(5X,≠INTECHANGE≠,5X,≠GRADE SIG.≠,5X,
     2≠GRADE STOP≠,5X,≠UNSIGNAL≠,5X,≠TOTAL≠//)
      WRITE(6,160)IN1,IN2,IN3,IN4,ITOT
160   FORMAT(5X,I5,10X,I5,10X,I5,10X,I5,8X,I5)



      WRITE(6,170)
170   FORMAT(5X,≠NO BRIDGES≠,5X,≠9 FT. AREA≠,5X,≠10FT AREA≠
     2,6X,≠11 FT AREA≠,5X,≠TOTAL AREA≠//)
      WRITE(6,180)BNB,B9,B10,B11,BA
180   FORMAT(5X,F10.0,5X,F10.2,5X,F10.2,
     25X,F10.2,5X,F10.2)
      STOP
      END
```

PROGRAM 6

FOR INTERSTATE HIGHWAYS

TO CALCULATE ADDITIONAL PAVEMENT AND BRIDGE AREA
TO WIDEN SHOULDERS TO SDHTP POLICY.

I=URBAN/RURAL CODE, N=HIGHWAY CODE, L=SECTION LENGTH
M1=RIGHT SHOULDER WIDTH, M2=LEFT SHOULDER WIDTH,
K=JURISDICTIONAL RESPONSIBILITY, K1=SURFACE TYPE,
IT=2000 ADT, NO=NUMBER OF BRIDGES ON SECTION.

```
      PROGRAM MAIN(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
      N4R=N4F=N6R=N6F=N8R=N8F=N10R=N10F=0
      NSR=NSF=NXR=NXF=NX=X=0
      X4R=X4F=X6R=X6F=X8R=X8F=0
      X10R=X10F=XR=XF=XRT=XFT=XLEN=0
      A4R=A4F=A6R=A6F=A8R=A8F=0
      A10R=A10F=AXR=AXF=AR=AF=0
      NB=B4=B6=B8=B10=BS=BTOT=0
      WRITE(6,10)
      FORMAT(1H1,5X,*SHD. WIDTH*,5X,*NO. OF SEC*,5X,*LENGTH MI.*
     2,10X,*ADD. AREA*//)
0     READ(5,30,END=150)I,N,K,L,M1,M2,K1,IT,NO
0     FORMAT(I1,24X,I2,3X,I1,I4,15X,I2,I2,2X,I2,56X,I6,I2)
      IF(I.EQ.2) GO TO 35
      GO TO 20
5     IF(K.LE.2) GO TO 40
      GO TO 20
0     IF(N.EQ.1) GO TO 50
      GO TO 20
0     NX=NX+1
      XLEN=XLEN + L/100.
      NB=NB + NO
      IF(M2.GT.0) GO TO 130
      IF (IT.GT.590) GO TO 70
      IF(M1.GT.4) GO TO 20
      B4=B4 + (4.-M1)*2.
      IF(K1.LE.60) GO TO 60
      N4R=N4R + 1
      A4R=A4R + (4.-M1)*L*11.7333
      X4R=X4R + L/100.
      GO TO 20
0     N4F=N4F + 1
      A4F=A4F + (4.-M1)*L*11.7333
      X4F=X4F + L/100.
      GO TO 20
0     IF(IT.GT.1100) GO TO 90
      IF(M1.GE.6) GO TO 20
      B6=B6 + (6.-M1)*2.
      IF(K1.LE.60) GO TO 80
```

```
      N6R=N6R + 1
      A6R=A6R + (6.-M1)*L*11.7333
      X6R=X6R + L/100.
      GO TO 20
 0    N6F=N6F + 1
      A6F=A6F + (6.-M1)*L*11.7333
      X6F=X6F + L/100.
      GO TO 20
 0    IF(IT.GE.2200) GO TO 110



      IF(M1.GE.8.) GO TO 20
      B8=B8 + (8.-M1)*2.
      IF(K1.LE.60) GO TO 100
      N8R=N8R + 1
      A8R=A8R + (8.-M1)*L*11.733
      X8R=X8R + L/100.
      GO TO 20
 00   N8F=N8F + 1
      A8F=A8F + (8.-M1)*L*11.7333
      X8F=X8F + L/100.
      GO TO 20
 10   IF(M1.GE.10) GO TO 20
      B10=B10 + (10.-M1)*2.
      IF(K1.LE.60) GO TO 120
      N10R=N10R + 1
      A10R=A10R + (10.-M1)*L*11.733
      X10R=X10R + L/100.
      GO TO 20
 120  N10F=N10F + 1
      A10F=A10F + (10.-M1)*L*11.733
      X10F=X10F + L/100.
      GO TO 20
 130  X=M1 + M2
      IF(X.GE.14.) GO TO 20
      BS=BS + 14. - X
      IF(K1.LE.60) GO TO 140
      NSR=NSR + 1
      AXR=AXR + (14.-X)*L*11.7333
      XR=XR + L/100.
      GO TO 20
 140  NSF=NSF + 1
      AXF=AXF + (14.- X)*L*11.733
      XF=XF + L/100.
      GO TO 20
 150  BTOT=B4 + B6 + B8 + B10 + BS
      AR=A4R + A6R + A8R + A10R + AXR
      AF=A4F + A6F + A8F + A10F + AXF
      NXR=N4R + N6R + N8R + N10R + NSR
      NXF=N4F + N6F + N8F + N10F + NSF
      XRT=X4R + X6R + X8R + X10R + XR
```

```
      XFT=X4F + X6F + X8F + X10F + XF
      C1=#4 FT RIGID#
      C2=#4 FT FLEX#
      C3=#6 FT RIGID#
      C4=#6 FT FLEX.#
      C5=#8 FT RIGID#
      C6=#8 FT FLEX.#
      C7=#10FT RIGID#
      C8=#10 FT FLEX#
      C9=#FRER WIDTH#
      C10=#FREF WIDTH#
      C11=#TOT. RIGID#
      C12=#TOT. FLEX.#
      C13=#TOTAL#
      WRITE(6,160)C1,N4R,X4R,A4R
160   FORMAT(5X,A10,5X,I10,5X,F10.2,5X,F10.2)
      WRITE(6,160)C2,N4F,X4F,A4F
      WRITE(6,160)C3,N6R,X6R,A6R
      WRITE(6,160)C4,N6F,X6F,A6F
      WRITE(6,160)C5,N8R,X8R,A8R
      WRITE(6,160)C6,N8F,X8F,A8F
      WRITE(6,160)C7,N10R,X10R,A10R


      WRITE(6,160)C8,N10F,X10F,A10F
      WRITE(6,160)C9,N8R,XR,AXR
      WRITE(6,160)C10,N8F,XF,AXF
      WRITE(6,160)C11,NXR,XRT,AR
      WRITE(6,160)C12,NXF,XFT,AF
      WRITE(6,160)C13,NX,XLEN
      WRITE(6,170)NB,BTOT
170   FORMAT(5X,I10,5X,F10.2//)
      STOP
      END
```

```
C PROGRAM 7
C
C FOR PRINCIPAL ARTERIALS EXCLUDING INTERSTATE
C
C TO CALCULATE ADDITIONAL PAVEMENT AND BRIDGE AREA
C TO WIDEN SHOULDERS TO SDHTP POLICY.
C
C I=URBAN/RURAL CODE, N=HIGHWAY CODE, L=SECTION LENGTH
C M1=RIGHT SHOULDER WIDTH, M2=LEFT SHOULDER WIDTH,
C K=JURISDICTIONAL RESPONSIBILITY, K1=SURFACE TYPE,
C IT=2000 ADT, NO=NUMBER OF BRIDGES ON SECTION.
C
C
      PROGRAM MAIN(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
      N4R=N4F=N6R=N6F=N8R=N8F=N10R=N10F=0
      NSR=NSF=NXR=NXF=NX=X=0
      X4R=X4F=X6R=X6F=X8R=X8F=0
      X10R=X10F=XR=XF=XRT=XFT=XLEN=0
      A4R=A4F=A6R=A6F=A8R=A8F=0
      A10R=A10F=AXR=AXF=AR=AF=0
      NB=B4=B6=B8=B10=BS=BTOT=0
      WRITE(6,10)
10    FORMAT(1H1,5X,*SHD. WIDTH*,5X,*NO. OF SEC*,5X,*LENGTH MI.*
     2,10X,*ADD. AREA*//)
 20   READ(5,30,END=150)I,N,K,L,M1,M2,K1,IT,NO
 30   FORMAT(I1,24X,I2,3X,I1,I4,15X,I2,I2,2X,I2,56X,I6,I2)
      IF(I.EQ.2) GO TO 35
      GO TO 20
 35   IF(K.LE.2) GO TO 40
      GO TO 20
 40   IF(N.EQ.2) GO TO 50
      GO TO 20
 50   NX=NX+1
      XLEN=XLEN + L/100.
      NB=NB + NO
      IF(M2.GT.0) GO TO 130
      IF (IT.GT.590) GO TO 70
      IF(M1.GT.4) GO TO 20
      B4=B4 + (4.-M1)*2.
      IF(K1.LE.60) GO TO 60
      N4R=N4R + 1
      A4R=A4R + (4.-M1)*L*11.7333
      X4R=X4R + L/100.
      GO TO 20
 60   N4F=N4F + 1
      A4F=A4F + (4.-M1)*L*11.7333
      X4F=X4F + L/100.
      GO TO 20
 70   IF(IT.GT.1100) GO TO 90
      IF(M1.GE.6) GO TO 20
      B6=B6 + (6.-M1)*2.
      IF(K1.LE.60) GO TO 80
```

```
      N6R=N6R + 1
      A6R=A6R + (6.-M1)*L*11.7333
      X6R=X6R + L/100.
      GO TO 20
80    N6F=N6F + 1
      A6F=A6F + (6.-M1)*L*11.7333
      X6F=X6F + L/100.
      GO TO 20
90    IF(IT.GE.5200) GO TO 110



      IF(M1.GE.8.) GO TO 20
      B8=B8 + (8.-M1)*2.
      IF(K1.LE.60) GO TO 100
      N8R=N8R + 1
      A8R=A8R + (8.-M1)*L*11.733
      X8R=X8R + L/100.
      GO TO 20
100   N8F=N8F + 1
      A8F=A8F + (8.-M1)*L*11.7333
      X8F=X8F + L/100.
      GO TO 20
110   IF(M1.GE.10) GO TO 20
      B10=B10 + (10.-M1)*2.
      IF(K1.LE.60) GO TO 120
      N10R=N10R + 1
      A10R=A10R + (10.-M1)*L*11.733
      X10R=X10R + L/100.
      GO TO 20
120   N10F=N10F + 1
      A10F=A10F + (10.-M1)*L*11.733
      X10F=X10F + L/100.
      GO TO 20
130   X=M1 + M2
      IF(X.GE.14.) GO TO 20
      BS=BS + 14. - X
      IF(K1.LE.60) GO TO 140
      NSR=NSR + 1
      AXR=AXR + (14.-X)*L*11.7333
      XR=XR + L/100.
      GO TO 20
140   NSF=NSF + 1
      AXF=AXF + (14.- X)*L*11.733
      XF=XF + L/100.
      GO TO 20
150   BTOT=B4 + B6 + B8 + B10 + BS
      AR=A4R + A6R + A8R + A10R + AXR
      AF=A4F + A6F + A8F + A10F + AXF
      NXR=N4R + N6R + N8R + N10R + NSR
      NXF=N4F + N6F + N8F + N10F + NSF
```

```
      XRT=X4R + X6R + X8R + X10R + XR
      XFT=X4F + X6F + X8F + X10F + XF
      C1=≠4 FT RIGID≠
      C2=≠4 FT FLEX≠
      C3=≠6 FT RIGID≠
      C4=≠6 FT FLEX.≠
      C5=≠8 FT RIGID≠
      C6=≠8 FT FLEX.≠
      C7=≠10FT RIGID≠
      C8=≠10 FT FLEX≠
      C9=≠FRER WIDTH≠
      C10=≠FREE WIDTH≠
      C11=≠TOT, RIGID≠
      C12=≠TOT. FLEX.≠
      C13=≠TOTAL≠
      WRITE(6,160)C1,N4R,X4R,A4R
160   FORMAT(5X,A10,5X,I10,5X,F10.2,5X,F10.2)
      WRITE(6,160)C2,N4F,X4F,A4F
      WRITE(6,160)C3,N6R,X6R,A6R
      WRITE(6,160)C4,N6F,X6F,A6F
      WRITE(6,160)C5,N8R,X8R,A8R
      WRITE(6,160)C6,N8F,X8F,A8F
      WRITE(6,160)C7,N10R,X10R,A10R


      WRITE(6,160)C8,N10F,X10F,A10F
      WRITE(6,160)C9,NSR,XR,AXR
      WRITE(6,160)C10,NSF,XF,AXF
      WRITE(6,160)C11,NXR,XRT,AR
      WRITE(6,160)C12,NXF,XFT,AF
      WRITE(6,160)C13,NX,XLEN
      WRITE(6,170)NB,BTOT
170   FORMAT(5X,I10,5X,F10.2//)
      STOP
      END
```

```
C PROGRAM 8
C
C FOR ALL SYSTEMS EXCLUDING COUNTY ROADS
C
C TO CALCULATE ADDITIONAL PAVEMENT AND BRIDGE AREA
C TO WIDEN SHOULDERS TO SDHTP POLICY.
C
C I=URBAN/RURAL CODE, N=HIGHWAY CODE, L=SECTION LENGTH
C M1=RIGHT SHOULDER WIDTH, M2=LEFT SHOULDER WIDTH,
C K=JURISDICTIONAL RESPONSIBILITY, K1=SURFACE TYPE,
C IT=2000 ADT, NO=NUMBER OF BRIDGES ON SECTION.
C
C
      PROGRAM MAIN(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
      N4R=N4F=N6R=N6F=N8R=N8F=N10R=N10F=0
      N8R=N8F=NXR=NXF=NX=X=0
      X4R=X4F=X6R=X6F=X8R=X8F=0
      X10R=X10F=XR=XF=XRT=XFT=XLEN=0
      A4R=A4F=A6R=A6F=A8R=A8F=0
      A10R=A10F=AXR=AXF=AR=AF=0
      NB=B4=B6=B8=B10=B8=BTOT=0
      WRITE(6,10)
10    FORMAT(1H1,5X,*SHD. WIDTH*,5X,*NO. OF SEC*,5X,*LENGTH MI.*
     2,10X,*ADD. AREA*//)
 20   READ(5,30,END=150)I,N,K,L,M1,M2,K1,IT,NO
 30   FORMAT(I1,24X,I2,3X,I1,I4,15X,I2,I2,2X,I2,56X,I6,I2)
      IF(I.EQ.2) GO TO 35
      GO TO 20
 35   IF(K.LE.2) GO TO 40
      GO TO 20
 40   IF(N.LE.8) GO TO 50
      GO TO 20
 50   NX=NX+1
      XLEN=XLEN + L/100.
      NB=NB + NO
      IF(M2.GT.0) GO TO 130
      IF (IT.GT.590) GO TO 70
      IF(M1.GT.4) GO TO 20
      B4=B4 + (4.-M1)*2.
      IF(K1.LE.60) GO TO 60
      N4R=N4R + 1
      A4R=A4R + (4.-M1)*L*11.7333
      X4R=X4R + L/100.
      GO TO 20
 60   N4F=N4F + 1
      A4F=A4F + (4.-M1)*L*11.7333
      X4F=X4F + L/100.
      GO TO 20
 70   IF(IT.GT.1100) GO TO 90
      IF(M1.GE.6) GO TO 20
      B6=B6 + (6.-M1)*2.
      IF(K1.LE.60) GO TO 80
```

```
      N6R=N6R + 1
      A6R=A6R + (6.-M1)*L*11.7333
      X6R=X6R + L/100.
      GO TO 20
80    N6F=N6F + 1
      A6F=A6F + (6.-M1)*L*11.7333
      X6F=X6F + L/100.
      GO TO 20
90    IF(IT.GE.2200) GO TO 110


      IF(M1.GE.8.) GO TO 20
      B8=B8 + (8.-M1)*2.
      IF(K1.LE.60) GO TO 100
      N8R=N8R + 1
      A8R=A8R + (8.-M1)*L*11.733
      X8R=X8R + L/100.
      GO TO 20
100   N8F=N8F + 1
      A8F=A8F + (8.-M1)*L*11.7333
      X8F=X8F + L/100.
      GO TO 20
110   IF(M1.GE.10) GO TO 20
      B10=B10 + (10.-M1)*2.
      IF(K1.LE.60) GO TO 120
      N10R=N10R + 1
      A10R=A10R + (10.-M1)*L*11.733
      X10R=X10R + L/100.
      GO TO 20
120   N10F=N10F + 1
      A10F=A10F + (10.-M1)*L*11.733
      X10F=X10F + L/100.
      GO TO 20
130   X=M1 + M2
      IF(X.GE.14.) GO TO 20
      BS=BS + 14. - X
      IF(K1.LE.60) GO TO 140
      NSR=NSR + 1
      AXR=AXR + (14.-X)*L*11.733
      XR=XR + L/100.
      GO TO 20
140   NSF=NSF + 1
      AXF=AXF + (14.- X)*L*11.733
      XF=XF + L/100.
      GO TO 20
150   BTOT=B4 + B6 + B8 + B10 + BS
      AR=A4R + A6R + A8R + A10R + AXR
      AF=A4F + A6F + A8F + A10F + AXF
      NXR=N4R + N6R + N8R + N10R + NSR
      NXF=N4F + N6F + N8F + N10F + NSF
```

```
      XRT=X4R + X6R + X8R + X10R + XR
      XFT=X4F + X6F + X8F + X10F + XF
      C1=#4 FT RIGID#
      C2=#4 FT FLEX#
      C3=#6 FT RIGID#
      C4=#6 FT FLEX.#
      C5=#8 FT RIGID#
      C6=#8 FT FLEX.#
      C7=#10FT RIGID#
      C8=#10 FT FLEX#
      C9=#FRER WIDTH#
      C10=#FREF WIDTH#
      C11=#TOT. RIGID#
      C12=#TOT. FLEX.#
      C13=#TOTAL#
      WRITE(6,160)C1,N4R,X4R,A4R
160   FORMAT(5X,A10,5X,I10,5X,F10.2,5X,F10.2)
      WRITE(6,160)C2,N4F,X4F,A4F
      WRITE(6,160)C3,N6R,X6R,A6R
      WRITE(6,160)C4,N6F,X6F,A6F
      WRITE(6,160)C5,N8R,X8R,A8R
      WRITE(6,160)C6,N8F,X8F,A8F
      WRITE(6,160)C7,N10R,X10R,A10R


      WRITE(6,160)C8,N10F,X10F,A10F
      WRITE(6,160)C9,NSR,XR,AXR
      WRITE(6,160)C10,NSF,XF,AXF
      WRITE(6,160)C11,NXR,XRT,AR
      WRITE(6,160)C12,NXF,XFT,AF
      WRITE(6,160)C13,NX,XLEN
      WRITE(6,170)NB,BTOT
170   FORMAT(5X,I10,5X,F10.2//)
      STOP
      END
```

```
C PROGRAM 9
C
C FOR FARM TO MARKET SYSTEM
C
C TO CALCULATE ADDITIONAL PAVEMENT AND BRIDGE AREA
C TO WIDEN SHOULDERS TO SDHTP POLICY.
C
C I=URBAN/RURAL CODE, N=HIGHWAY CODE, L=SECTION LENGTH
C M1=RIGHT SHOULDER WIDTH, M2=LEFT SHOULDER WIDTH,
C K=JURISDICTIONAL RESPONSIBILITY, K1=SURFACE TYPE,
C IT=2000 ADT, NO=NUMBER OF BRIDGES ON SECTION.
C
C
      PROGRAM MAIN(INPUT1,INPUT2,OUTPUT,TAPE5=INPUT1,TAPE4=INPUT2
     2,TAPE6=OUTPUT)
      N4R=N4F=N6R=N6F=N8R=N8F=N10R=N10F=0
      NSR=NSF=NXR=NXF=NX=X=0
      X4R=X4F=X6R=X6F=X8R=X8F=0
      X10R=X10F=XR=XF=XRT=XFT=XLEN=0
      A4R=A4F=A6R=A6F=A8R=A8F=0
      A10R=A10F=AXR=AXF=AR=AF=0
      NB=B4=B6=B8=B10=BS=BTOT=0
      WRITE(6,10)
10    FORMAT(1H1,5X,*SHD. WIDTH*,5X,*NO. OF SEC*,5X,*LENGTH MI.*
     2,10X,*ADD. AREA*//)
 20   READ(5,30,END=150)I,D1,D2,N,K,L,M1,M2,K1,IT,NO
 30   FORMAT(I1,5X,A10,A5,4X
     2,I2,3X,I1,I4,15X,I2,I2,2X,I2,56X,I6,I2)
      IF(I.EQ.2) GO TO 35
      GO TO 20
 35   IF(K.LE.2) GO TO 40
      GO TO 20
40    IF(N.GT.2.AND.N.LE.8) GO TO 50
      GO TO 20
 50   READ(4,51,END=52)D3,D4
 51   FORMAT(A10,A5)
      IF(D1.EQ.D3.AND.D2.EQ.D4) GO TO 53
      GO TO 50
 52   REWIND 4
      GO TO 20
 53   REWIND 4
      NX=NX + 1
      XLEN=XLEN + L/100.
      NB=NB + NO
      IF(M2.GT.0) GO TO 130
      IF (IT.GT.590) GO TO 70
      IF(M1.GT.0) GO TO 20
      B4=B4 + (4.-M1)*2.
      IF(K1.LE.40) GO TO 60
      N4R=N4R + 1
      A4R=A4R + (4.-M1)*L*11.7333
```

```
      X4R=X4R + L/100.
      GO TO 20
60    N4F=N4F + 1
      A4F=A4F + (4.-M1)*L*11.7333
      X4F=X4F + L/100.
      GO TO 20
70    IF(IT.GT.1100) GO TO 90
      IF(M1.GE.6) GO TO 20
      B6=B6 + (6.-M1)*2.
      IF(K1.LE.60) GO TO 80



      N6R=N6R + 1
      A6R=A6R + (6.-M1)*L*11.7333
      X6R=X6R + L/100.
      GO TO 20
80    N6F=N6F + 1
      A6F=A6F + (6.-M1)*L*11.7333
      X6F=X6F + L/100.
      GO TO 20
90    IF(IT.GE.5200) GO TO 110
      IF(M1.GE.8.) GO TO 20
      B8=B8 + (8.-M1)*2.
      IF(K1.LE.60) GO TO 100
      N8R=N8R + 1
      A8R=A8R + (8.-M1)*L*11.733
      X8R=X8R + L/100.
      GO TO 20
100   N8F=N8F + 1
      A8F=A8F + (8.-M1)*L*11.7333
      X8F=X8F + L/100.
      GO TO 20
110   IF(M1.GE.10) GO TO 20
      B10=B10 + (10.-M1)*2.
      IF(K1.LE.60) GO TO 120
      N10R=N10R + 1
      A10R=A10R + (10.-M1)*L*11.733
      X10R=X10R + L/100.
      GO TO 20
120   N10F=N10F + 1
      A10F=A10F + (10.-M1)*L*11.733
      X10F=X10F + L/100.
      GO TO 20
130   X=M1 + M2
      IF(X.GE.14.) GO TO 20
      BS=BS + 14. - X
      IF(K1.LE.60) GO TO 140
      NSR=NSR + 1
      AXR=AXR + (14.-X)*L*11.733
      XR=XR + L/100.
      GO TO 20
```

```
140   NSF=NSF + 1
      AXF=AXF + (14.- X)*L*11.733
      XF=XF + L/100.
      GO TO 20
150   BTOT=B4 + B6 + B8 + B10 + BS
      AR=A4R + A6R + A8R + A10R + AXR
      AF=A4F + A6F + A8F + A10F + AXF
      NXR=N4R + N6R + N8R + N10R + NSR
      NXF=N4F + N6F + N8F + N10F + NSF
      XRT=X4R + X6R + X8R + X10R + XR
      XFT=X4F + X6F + X8F + X10F + XF
      C1=≠4 FT RIGID≠
      C2=≠4 FT FLEX≠
      C3=≠6 FT RIGID≠
      C4=≠6 FT FLEX.≠
      C5=≠8 FT RIGID≠
      C6=≠8 FT FLEX.≠
      C7=≠10FT RIGID≠
      C8=≠10 FT FLEX≠
      C9=≠FRER WIDTH≠
      C10=≠FREF WIDTH≠
      C11=≠TOT. RIGID≠
      C12=≠TOT. FLEX.≠


      C13=≠TOTAL≠
      WRITE(6,160)C1,N4R,X4R,A4R
160   FORMAT(5X,A10,5X,I10,5X,F10.2,5X,F10.2)
      WRITE(6,160)C2,N4F,X4F,A4F
      WRITE(6,160)C3,N6R,X6R,A6R
      WRITE(6,160)C4,N6F,X6F,A6F
      WRITE(6,160)C5,N8R,X8R,A8R
      WRITE(6,160)C6,N8F,X8F,A8F
      WRITE(6,160)C7,N10R,X10R,A10R
      WRITE(6,160)C8,N10F,X10F,A10F
      WRITE(6,160)C9,NSR,XR,AXR
      WRITE(6,160)C10,NSF,XF,AXF
      WRITE(6,160)C11,NXR,XRT,AR
      WRITE(6,160)C12,NXF,XFT,AF
      WRITE(6,160)C13,NX,XLEN
      WRITE(6,170)NB,BTOT
170   FORMAT(5X,I10,5X,F10.2//)
      STOP
      END
```

HPMS Record Format

Part I: All Sections

Position	Item	Length			Rural Only	Urban Only
1	57	1		*Rural/Urban Code		
2-3	1	2		Year		
4-5	2	2		State Code		
6	3	1		Type of Section ID		
7-9	6	3		County Code (FIPS County Code)		
10-21	4	12		Section ID		
22	5	1		Segment (Precoded: 0)		
23-25	7	3		Urban Area Code		✓
26-27	8	2		Functional Class		
28-29	46	2		Volume Group Identifier		
30	9	1		Federal-Aid System		
31	10	1		Jurisdictional Responsibility		
32-35	11	4	(xx.xx)	Section Length		
36-39	47	4	(xx.xx)	Expansion Factor		
40	12	1		Access Control		
41-42	13	2		Number of Through Lanes		
43-44	14	2		Lane Width		
45-47	15	3		Approach Width		✓
48-49	16	2		Median Width		
50	17	1		Median Type		
51-54	18A&B	4		Shoulder Width (Right A, Left B)		
55	19	1		Shoulder Type		
56	20	1		Drainage Adequacy		
57-58	21	2		Surface Type		
59	22	1		Pavement Section		
60-61	23	2		Structural Number		
62-63	24	2	(x.x)	Pavement Condition		
64-65	25	2		Skid Resistance		
66-67	26	2		Number Grade-Separated Interchanges		
68-69	27A	2		At-Grade Intersections: Signals		
70-71	27B	2		Stop Signs		
72-73	27C	2		Other or None		
74	28	1		Prevailing Type of Signalization		✓
75-76	29	2		% Green Time		✓
77-78	30	2		Number Entrances/Exits		
79	31	1		Type of Development		
80	32	1		Urban Location		✓
81	33	1		Terrain	✓	
82-84	34	3		Existing Right-of-Way		
85	35	1		Is Widening Feasible?		
86-91	36	6		1978ADT		
92-93	37A	2		% Trucks: Peak		
94-95	37B	2		Off-Peak		
96-97	38	2		K-Factor		
98-100	39	3		Directional Factor		

*Column 79 Card 1 on worksheets 1-Urban; 2-Rural

(continued)

C-2

Position	Item	Length		Rural Only	Urban Only
101-102	40	2	*Type of Operation		✓
103	41A	1	Parking: Peak		✓
104	41B	1	Off-Peak		✓
105-109	42A	5	Capacity: Peak		
110-114	42B	5	Off-Peak		✓
115-120	43	6	2000 ADT		
121-122	44	2	Number Structures		
123-124	45	2	Number of At-Grade R.R. Crossings		
125-126	48	2	Speed Limit		
127-129	49	3	PSD $\geq$ 1500	✓	
130	50	1	Horizontal Alignment	✓	
131	51	1	Vertical Alignment	✓	
132-133	52	2	Average Highway Speed		
134-139	-	6	Continuation Code for Optional Data (6 positions coded zero; No optional data)		

*Type of Operation coded "0" is coded "10" on the tape record.

A State not submitting any of the optional data (cards 3-6) would submit data in the above 139 character record format with position 134-139 always coded "000000".

STATE DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION
TEXAS ROAD MILEAGE SUMMARY

As of December 31, 1978

HIGHWAY SYSTEM	TYPE OF AID SYSTEM	MILES DESIGNATED AS OF THIS DATE	STATE MAINTAINED MILEAGE		CITY MAINTAINED MILEAGE
			RURAL	URBAN	
INTERSTATE	FAI	3,215	2,214	870	0
U.S. AND STATE HIGHWAYS	FAP	16,765	14,091	2,368	6
	FAM	1,617	123	1,345	118
	FAS	8,270	7,544	651	0
	NON-FA	701	312	162	10
	Total	27,353	22,070	4,526	134
FARM OR RANCH TO MARKET AND RECREATIONAL ROADS	FAP	114	91	23	0
	FAM	1,132	196	885	20
	FAS	24,525	23,246	958	0
	NON-FA	15,615	14,636	439	1
	Total	41,386	38,169	2,305	21

Miles on Highway System for Rural Roads*

Group	Interstate	Other Principal Arterials	Minor Arterials	Major Collectors	Minor Collectors
1	1174.461	5639.690	4932.625	31752.909	14124.841
2	807.973	1998.231	1756.405	1623.116	208.564
3	198.674	267.761	277.228	489.759	49.165
4	23.249	87.901	19.391	85.505	16.970
5	19.858	76.584	0.0	1.361	5.972
6	10.672	9.496	0.0	0.0	5.931
7	0.0	0.999	0.0	0.0	0.0
8	0.0	1.717	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0
Total	2234.887	8082.379	6985.649	33952.650	14411.443

* Federal Aid Rural (includes mileage in cities < 5000 population).

Bridges Outside Incorporated Cities
by
Functional Classification

Func-Class	Bridge Count
	184
01	2,824
02	3,852
03	2,496
04	7,584
05	3,720
11	23
12	12
13	78
14	35
15	11
21	5
23	11
24	6
25	4
41	147
42	88
43	101
44	65
45	52
Total	2,298

COUNT ON BRIDGE LENGTH
BY TYPE OF HIGHWAY

(Excluding Bridges Greater Than 1000 Feet)

Type	Number	Total Length, ft	Average Length, ft
Interstate	6542	1,223,478	187.02
US and State	6647	1,052,667	157.37
Farm to Market	124	14,551	117.35