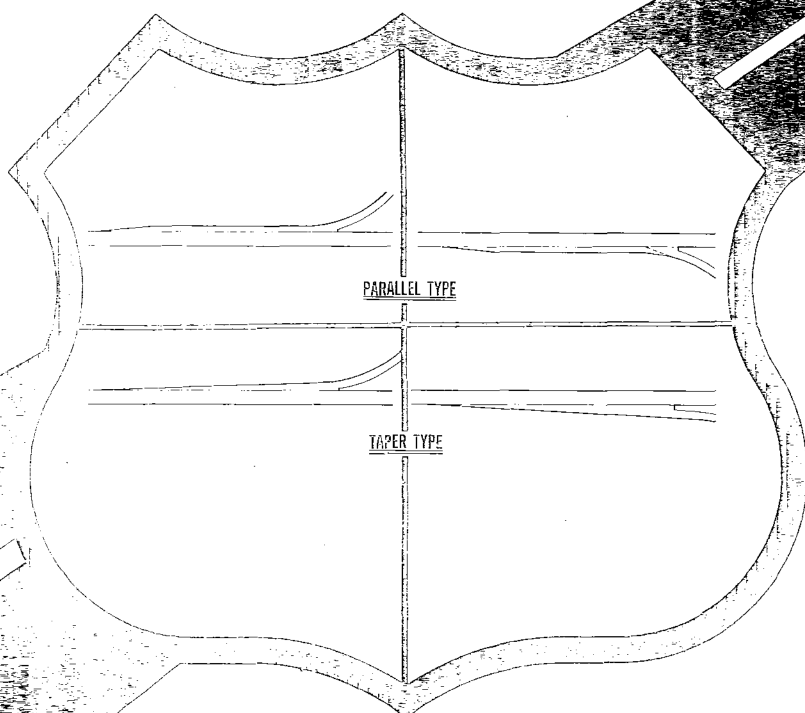
Report No. FHWA-RD-79-127

PB81-194433

IMPROVING THE TRAFFIC OPERATIONS AND SAFETY OF RAMPS AND SPEED CHANGE LANES— A Review of State Design Practices

September 1980

Interim Report



Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

Prepared for

FEDERAL HIGHWAY ADMINISTRATION

Offices of Research & Development

Environmental Division

Washington, D.C. 20590

FOREWORD

This report summarizes the results of a State-of-the-Art analysis of ramps and speed change lanes as presented in various State design manuals. The report will be of interest to highway design and traffic engineers concerned with highway design standards for ramps and speed change lanes of interchanges.

The report presents the interim findings of contract DOT-FH-11-9183, "Improving the Traffic Operations and Safety of Ramps and Speed Change Lanes." The study is being conducted for the Federal Highway Administration, Environmental Division, Office of Research in Washington, D.C. as part of Project 1J, "Improved Geometric Design" of the Federally Coordinated Program (FCP) of Research and Development. Mr. George B. Pilkington, II is the Project Manager.

Sufficient copies of this report are being distributed to provide a minimum of one copy to each FHWA regional office, one to each FHWA division office and two to each State highway agency. A limited number of copies are available for official use from the Environmental Division, HRS-43, Federal Highway Administration, Washington, D.C. 20590.

Charles F. Scheffey
for Director, Office of Research
Federal Highway Administration

NOTICE

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

The contents of this report reflect the views of the contracting organization, which is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policy of the Department of Transportation. This report does not constitute a standard, specification, or regulation.

The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein only because they are considered essential to the object of this document.

Technical Report Documentation Page

1. Report No. FHWA-RD-79-127	2. Government Accession No.	3. Recipient's Catalog No. PB81 194433
4. Title and Subtitle IMPROVING THE TRAFFIC OPERATIONS AND SAFETY OF RAMPS AND SPEED CHANGE LANES - A Review of State Design Practices		5. Report Date September 1980
		6. Performing Organization Code
7. Author(s) Michael Baker, Jr., Inc.		8. Performing Organization Report No.
9. Performing Organization Name and Address Michael Baker, Jr. Inc. 4301 Dutch Ridge Road Beaver, PA 15009		10. Work Unit No. (TRAIS) FCP 31J4022
		11. Contract or Grant No. DOT-FH-11-9183
12. Sponsoring Agency Name and Address Federal Highway Administration Office of Research Environmental Division Washington, D.C. 20590		13. Type of Report and Period Covered Interim Report
		14. Sponsoring Agency Code E0512

15. Supplementary Notes

FHWA Contract Manager - Ronald E. Boenau (HRS-43)

16. Abstract

This interim report presents the results of a review of ten selected state highway design manuals, discussions with state design and traffic operation engineers and a literature review with specific attention given to ramp and speed change lane criteria. For comparison, additional documents from the American Association of State Highway and Transportation Officials (AASHTO) and Canada were reviewed. A summary of the review and analysis of the manuals is provided along with a detailed discussion of selected design parameters of ramps and speed change lanes.

The review determined that the manner in which individual design elements are fitted together can be improved by providing that a complete section of roadway (e.g. a ramp) be designed to insure a proper smooth speed transition (SST) exists. This can be done by studying a proposed design from beginning to end and recording the speed transitions expected.

17. Key Words Acceleration lanes, Deceleration lanes, Highway design, Interchanges, Ramps, Speed change lanes, Traffic operations		18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161.	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 43	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION AND PROBLEM STATEMENT

INTRODUCTION

The following pages summarize a portion of the work accomplished for the research project, "Improving Traffic Operations and Safety of Ramps and Speed Change Lanes," Contract No. DOT-FH-11-9183. The agreement between Michael Baker, Jr., Inc., and the Federal Highway Administration was initiated on September 30th, 1976 and will be performed over a 36-month period. This work has been developed after the review of several related states' practices.

This document is organized into three major sections followed by a preliminary bibliography of reviewed material. These sections are defined as follows:

I. Introduction and Problem Statement

An overview of the project mechanics and the statement of the problems leading to initiation of the research.

II. Research Objectives

A concise description of the goals of the research.

III. A Preliminary Overview of the State-of-the-Art

An analysis of the information gathered thus far from the review of several selected state design manuals.

PROBLEM STATEMENT

The application of even the latest highway design criteria can lead to freeway to arterial interchanges which operate either unsafely or inefficiently.

The inefficient operation, broadly defined here as lack of capacity, can be caused by two conditions: (1) Incorrectly predicting traffic demand; or (2) A "designed in" capacity restraint possibly due to topographic, land use, environmental or other site-specific shortcomings. These two conditions are generally both present in any real world situation.

The unsafe operation, evidenced by high incidence of erratic manuevers and accidents, can be caused by four conditions: (1) High congestion which increases the likelihood of vehicular conflict; (2) Vehicle malfunction or failure (3) Poor geometric design--design which for a relatively high proportion of drivers is in conflict with the ability of the driver to avoid a collision or accident and (4) Driver error. At specific unsafe urban areas these conditions are probably present together.

The problem addressed in this research focuses upon geometric criteria and the impact which design has upon safety and operation of freeway to arterial ramps. Even with the latest criteria, accidents, that could be avoided with better geometrics, take place on freeway to arterial ramps. These accident problems are of course compounded by capacity problems inherent in the specific design.

Essentially the inherent safety problem on ramps is one of individual vehicular speeds which are incompatible with either the geometric design assumptions or the speeds of average traffic streams. For example, the driver may attempt to exit at speeds higher than permitted by the design or enter the freeway at speeds lower than the average freeway operating speed. Endless examples of speed inequalities versus design or operation speed restrictions could be given for the freeway to arterial ramp case. These speed inequalities cause accidents.

Speed differentials in freeway to arterial ramps are inherent in the ramp operation. That is, freeway to arterial ramps serve only two basic purposes: to permit the driver to change direction and to change speed. By definition and through deliberate design, the freeway and arterial street operate at different speeds.

The safety and operations problems of ramps and speed change lanes can best be examined by looking at the speed transitioning properties of alternative designs. The ramp system must be designed in such a fashion so as to permit desirable speed transitions between freeways and arterials. The geometric design should allow this transition. It may be possible and desirable to use design components to control speeds within the ramp area. Thus, the geometrics of the ramp system can communicate to the driver the fact that a speed transition is required.

In general, the problem can be best stated in terms of speed conflicts--conflicts between what the driver wants to do, what the driver should do and what the design allows him to do. These various conflicts show up as accidents and erratic manuevers on freeway to arterial ramps and speed change lanes. Therefore by examining the vehicular speeds which occur on various types of ramp designs, it will be possible to determine the relative safety of alternative design philosophies and standards. The basic objectives of the research project are built around this concept of speed conflicts being indicative of poor design and high accident potential.

II. RESEARCH OBJECTIVES

The listing of the research objectives which follows is simply a verbatum reproduction of those listed by the Federal Highway Administration in the project Prospectus although Objective 5 has been added to the original list. This added objective represents a contract modification requested by FHWA in January, 1977.

Objective 1. To develop an optimum standard methodology and design criteria for use in designing and constructing both new and existing ramps and speed change lanes freeway-arterial highway interchanges based upon a literature review and analysis and utilizing cost-effective and energy conservation techniques.

Objective 2. To identify and observe operational characteristics of test facilities which can be used to evaluate the methodology and design criteria established in Objective 1.

Objective 3. To determine the revisions required to implement the proposed methodology and criteria and to examine the probability of acceptance and application by users in planning, designing and constructing ramps and speed change lanes.

Objective 4. To delineate procedures required for acceptance and adoption of proposed revisions into practice and to prepare a supplemental manual of geometric design criteria for ramps and speed change lanes which incorporate these proposed revisions.

Objective 5. To quantify the accident problem on ramps and speed change lanes using the Interstate System Accident (ISAR) Data.

III. A PRELIMINARY OVERVIEW OF THE STATE-OF-THE-ART

PURPOSE

Prior to finalizing the experimental work program first advanced in the proposal an analysis of the current state of the art was made. This activity represented Task 1 of the six task research program. It was to be completed before submitting the work program so that the researchers could verify that their view of the problem defined in the original proposal was consistent with published literature and other professional opinions.

This section of the work program is an overview of the state of the art review which has been accomplished in Task 1. The intention of this section is to show how the published literature (both research reports and design manuals) and the opinions of design engineers from five states support or refute our intended work program.

INPUTS INTO THE STATE-OF-THE-ART

The research team relied on three major information areas to produce the following summary of the State-of-the-Art. These included:

(1) State design manuals

(2) Research literature

(3) Discussions with state design engineers

All design manuals which are on file at FHWA's Office of Engineering Highway Design Divison were reviewed to determine their general organization and similarity to existing AASHTO* guidelines. A list of eleven states was established and design manuals from each were obtained and reviewed in depth. The design manual from Canada, the AASHTO* "Red Book" and Blue Book were also included in the analysis.

---

*Throughout this document references will be made to AASHTO, the "Red Book" and "Blue Book". The accurate name of this organization and the books which they've published are listed below:

AASHTO - American Association of State Highway and Transportation Officials.

Red Book - A Policy on Design of Urban Highways and Arterial Streets (1973).

Blue Book - A Policy on Geometric Design of Rural Highways (1965).

The research literature search was initiated using the computerized "Highway Research Information Service" (HRIS) file search mechanism. The Department of Transportation's Library in Washington was used as the primary source for the pertinent reports identified through the HRIS search.

Five states were visited by the Principal Investigator and Assistant Principal Investigator so that the proposed project could be discussed with practicing design engineers. A common structured discussion format was used for each meeting and detailed resumes of the comments received were prepared and distributed by the research staff.

An outline of the lessons learned from each of these information sources is presented in the following sections. Because the research staff will continue to monitor research reports and state design procedure changes as well as continue informal dialogue with the state engineers who were contacted, the following description of the state-of-the-art is preliminary. It is hoped that the brief discussion which follow will serve as a logical preface to the detailed work program in Section IV.

DESIGN MANUAL REVIEW

SUMMARY

An initial cursory review of twenty selected state design manuals was done by the project staff in Washington, D.C. at the FHWA Office of Engineering, Highway Design Division, Room 3124 in the Nassif Building during the week of December 6, 1976. A very cursory review was also given to the standard construction drawings of most of these same states during the same time that the design manuals were reviewed.

During the design manual review, specific attention was given to the criteria governing design of ramps and speed change lanes in order to concentrate on the main subject of the research ramps and speed change lanes. Those manuals which exhibited the most comprehensive coverage of these components were noted. This quality was combined with the following factors in order to best attempt to reduce the twenty state design manuals reviewed to approximately ten for further study. The additional factors considered were: 1) the states' geographical location, 2) the states with major metropolitan areas, 3) the states whose reputation indicates innovative or outstanding design philosophies and 4) the states whose criteria and/or personnel are more familiar to the consultant from previous highway design and/or research. After evaluating the above, design manuals of eleven states (and Canada) were obtained by the consultant for a more detailed examination and evaluation.

In addition to these eleven states and Canada, a detailed review was performed for similar criteria of the American Association of State Highway and Transportation Officials (AASHTO) two major design policy books, 1) "Policy on Geometric Design of Rural HIghways" (the Blue Book) 1965 and 2) "Policy on Design of Urban Highways and Arterial Streets" (the Red Book) 1973. The Red Book was reviewed in more detail, especially Part III, HIGHWAY DESIGN. The reason for emphasis on the Red Book review was that this project is to deal primarily with urban freeway to arterial interchange ramps and speed change lanes and that the Red Book is more recent (1973) than the Blue Book (1965). The FHWA has also issued a notice (N-5040.14 of September 2, 1975) which states that the Red Book is to be used whenever its policy differs from the Blue Book.

Reviewing the twelve various design manuals and two AASHTO policy books was a trying and time consuming task. The intent was to attempt to find appropriate ramp and speed change lane criteria for comparative purposes. Each design manual and policy book format was different. There were also a few instances where the design manual guidelines were not common design practice with the states themselves, e.g. spiral policies on when and where they should be used. The manual would recommend use of spirals but in actual design practice they were seldom used by the agency.

The following is a brief summary of the findings on selected design topics reviewed in each of the fourteen design agency publications. The summary indicates how each of the topics compares with the AASHTO Red Book. The topics were chosen from a review of the Red Book and considered the most significant design elements to be considered when designing a freeway-arterial interchange. A more detailed discussion of each topic follows later in this report in the order presented below.

HORIZONTAL CURVE CRITERIA FOR FREEWAY-ARTERIAL RAMPS WITH A 30 MPH DESIGN SPEED

Refer to Table 1.

<u>Curve Radius</u>

The AASHTO Red Book recommends 250 feet with an 8% superelevation rate. Ranges were from 230-300 feet. The most common was 250 feet.

<u>Corresponding Superelevation Rates</u>

Ranges were from 5%-12% depending on geographical locations. 8% was predominate favorite.

Maximum Superelevation Rates

See "b" above.

Runoff

Runoff Relative Slope Ratios - The AASHTO Red Book recommends a 1:150 ratio between profiles of the baseline and the transitioning edge of pavement. Ranges were from 1:104 to 1:167 with 1:150 the general favorite.

Runoff Length - Lengths depend on cross slope rate changes, pavement widths and recommended relative slope ratios. Lengths varied from 67 feet to 200 feet. The AASHTO Red Book length was calculated to be 144 feet.

Runoff Treatment - The AASHTO Red Book and almost all of the other design agencies recommended that runoff transitioning be done on a spiral or where no spiral is used, place approximately 2/3 of the runoff on the tangent and 1/3 within the horizontal curve.

Lane Width

Using AASHTO's Case I, Condition C, widths ranged from 12 to 16 feet with the overwhelming favorite being 16 feet, similar to the AASHTO Red Book recommendation.

Normal Crown

The AASHTO Red Book recommends a 1%-2% cross slope rate. All the agencies fell within this range and most favored values nearer to the upper limit.

SPIRALS

Refer to Table 2.

The AASHTO Red Book encourages the use of spirals between tangents and circular curves and also between compound curves. Most of the other design agencies reviewed do not consider that the advantages of spirals are beneficial enough to specifically require them in their roadway design criteria. This is particularly true of ramps.

PROFILE GRADES

Refer to Table 3.

Although there is a substantial difference in terrain among the various design agencies reviewed, there is considerable uniformity in their recommended maximum and minimum grade line percentages when compared with the AASHTO Red Book.

STOPPING SIGHT DISTANCE

Refer to Table 4.

There is almost complete conformity with the AASHTO Red Book minimum and desirable stopping sight distance criteria. None of the agencies recommended less than the Red Book for the 30, 50 and 70 MPH design reviewed.

ACCELERATION AND DECELERATION LANE LENGTHS

Acceleration Lane Lengths

Refer to Figure 1 and Table 5.

Only two of the design agencies reviewed conforms with the minimum length (1330 feet) recommended by the AASHTO Red Book method of measurement for a 30 MPH ramp to a 70 MPH freeway. All the other agencies use either shorter lengths or the AASHTO Blue Book method of measurement (which includes the lane's taper in its length). The Red Book does not include the taper in its length measurement.

Almost all of the design agencies reviewed preferred the taper type acceleration lane over the parallel type.

Deceleration Lane Lengths

Refer to Figure 2 and Table 6.

Seven of the design agencies reviewed conform with the minimum length (510 feet) recommended by the AASHTO Red Book method of measurement for a 70 MPH freeway to a 30 MPH ramp. All other agencies use either shorter lengths or the AASHTO Blue Book method of measurement (which includes the lane's taper in its length). The Red Book does not include the taper in its length measurement.

The design agencies reviewed preferred the taper type deceleration lane over the parallel type by a narrow margin (8:6).

TWO LANE ENTRANCE AND EXIT TERMINALS

Two Lane Entrance Terminal

Refer to Figure 3 and Table 7.

The AASHTO Red Book shows two types of two lane entrance terminals, a parallel type and a taper type.

Only three of the design agencies reviewed meet the Red Book recommended minimum length (3400 feet) for a parallel type terminal. Only one agency meets the recommended taper type minimum length (3,200 feet). Three of the agencies have no specific criteria in their design manuals for either method.

The parallel type terminal was the predominate favorite type used by those agencies which have specific criteria.

Two Lane Exit Terminals

Refer to Figure 4 and Table 8.

Both a parallel and taper type design is shown in the AASHTO Red Book for two lane exit terminals.

None of the design agencies reviewed meet the Red Book recommended minimum length (2100 feet) for a parallel type terminal and only two meet the Red Book taper type criteria (1,972 feet).

The taper type terminal was the predominate favorite type used by those agencies reviewed which have specific criteria.

RAMP PAVEMENT, PAVED SHOULDER AND STRUCTURE WIDTHS

Refer to Table 9.

Ramp Pavement Widths

The AASHTO Red Book ramp pavement width recommendations vary with the curve radii, i.e. the sharper the curve, the wider the pavement (15 to 23 feet). Most of the design agencies reviewed generally follow the Red Book recommendations. Only two states' criteria differed substantially from the Red Book.

Paved Shoulder Widths

Although there is considerable variation among the design agencies criteria, all the agencies reviewed have criteria which falls within the recommended limits of the AASHTO Red Book for the left shoulders (2 to 4 feet). Only two of the agencies reviewed fail to meet the Red Book right shoulder recommended criteria (6 to 8 feet).

Structure Widths

The AASHTO Red Book recommends to carry at least the ramp pavement plus the paved shoulders width across a structure. Most of the design agencies reviewed recommend a similar criteria.

FRONTAGE ROADS

Practically all the design agencies reviewed consider frontage road usage based upon economic justifications and for the reasons noted in the AASHTO Red Book. One state was somewhat unique in their more liberal use of frontage roads, and especially in urban areas where there is sufficient right-of-way to permit their use.

CLEARANCES AT UNDERPASSES

Lateral Clearances

Practically all the design agencies reviewed conform to the AASHTO Red Book policy of providing a minimum opening for freeways and ramps which includes the median (when practical), pavement and shoulders. The 30 foot wide clear recovery area from the edge of the travel lane has become a widely cited desirable guide dimension.

Vertical Clearances

The AASHTO Red Book recommends minimum vertical clearances of 14 feet to 16 feet, depending on the type highway. All the design agencies reviewed conform to these same recommendations.

DISTANCE BETWEEN SUCCESSIVE RAMP TERMINALS

Refer to Table 10.

Distance Between Successive Exit Terminals

The AASHTO Red Book recommends a minimum 1000 feet on freeways. Only five of the design agencies reviewed meet this criteria and no criteria could be found for five of the agencies. The others reviewed specified shorter minimum lengths.

Distance Between Successive Exit-Entrance Terminals

The AASHTO Red Book recommends a minimum 500 feet. Only three of the design agencies reviewed meet (or exceed) this criteria. No policy could be found for six agencies and three used less than the AASHTO minimum distance.

Distance Between Sucessive Entrance Terminals

No specific criteria could be found in the AASHTO Red Book. The AASHTO Blue Book recommends a minimum 500 feet and desirable 900 feet. Five other design agencies reviewed provide similar (or longer) criteria. No specific policy could be found for the remaining six agencies, although one says the situation requires special design considerations.

Distance Between Successive Entrance-Exit Terminals

The AASHTO Red Book recommends that weaving requirements govern, but lists a desirable distance as not less than 1000 feet. Ten of the design agencies reviewed have similar policies while no specific criteria could be found for the two remaining agencies.

UNIFORMITY OF INTERCHANGE PATTERNS

The AASHTO Red Book recommends that when a series of interchanges is being designed along a route, uniformity of pattern and its effect on operation of the interchange should be considered, especially in urban areas. They further note that the simplest and most common type interchange for urban use is the diamond. Practically all the design agencies reviewed seem to have adopted this general policy.

FREEWAY OVER VERSUS UNDER

The AASHTO Red Book does not address this topic. The Blue Book indicates each interchange must be studied in detail to determine which roadway should go over or under. Only one of the other design agencies reviewed addresses this topic in their design manual. They recommend that the freeway pass under the sideroad whenever practical. One of the agencies verbally indicated that they almost always prefer the freeway to pass over the sideroad in flat areas to reduce right of way damages.

PRINCIPAL FINDINGS OF DESIGN MANUAL REVIEWS

The following sections present a detailed description of the selected design topics reviewed. The findings of these topics have been summarized in the previous section. The selected topics reviewed were:

1. Horizontal Curve Criteria for Freeway-Arterial Ramps

2. Spirals

3. Profile Grades

4. Stopping Sight Distance
5. Acceleration and Deceleration Lanes
6. Two Lane Entrance and Exit Terminals
7. Ramp Pavement, Paved Shoulder and Structure Widths
8. Frontage Roads
9. Clearances at Underpasses
10. Distance Between Successive Ramp Terminals
11. Uniformity of Interchange Patterns
12. Freeway Over Versus Under

Descriptions, figures, tables and comparisons with the AASHTO Red and Blue Book design policy guides are presented for the above noted topics. Where tables are presented, each of the fourteen design agencies reviewed are listed vertically with the various components of the specific design element being reviewed shown horizontally across the top of the table. Figures were added to complement the tables wherever they were determined to be necessary and/or beneficial to the explanation.

All dimensional units have been presented in the English system to coincide with the practice found in the manuals and the AASHTO books. The final report will show both English and Metric units.

A complete bibliography has been included in the appendix of this work plan for easy reference to the two AASHTO policy books and twelve design manuals reviewed.

HORIZONTAL CURVE CRITERIA FOR FREEWAY-ARTERIAL RAMPS

Table 1 illustrates that there is considerable variation in horizontal curve criteria for freeway-arterial ramps when comparing the eleven states, Canada and the AASHTO Red and Blue Books. For comparative purposes, a 30 MPH design speed curve has been selected to illustrate the criteria differences. The following is a summary of these differences.

Curve Radius - The circular curve radii range from 230'-300'. The most common was 250', the same as recommended by AASHTO when using an 8% superelevation rate.

Superelevation - Recommended full superelevation cross slopes range from 5%-12% with 8% dominating as the favorite for this design speed curve.

TABLE I

HORIZONTAL CURVE CRITERIA FOR FREEWAY RAMPS

DESIGN AGENCY	SPEED (MPH)	Curve Radius (Ft.)	Super-elevation (%)	Max. S.E. Allowable (%)	Runoff: Relative Slope Ratio*	Runoff: Length** (Ft.)	Runoff: Treatment	Lane*** Width (Ft.)	Normal Crown (%)
AASHTO Red	30	250 (p. 329)	8 (p. 329)	8 (Assumed) (p. 329)	1:150 (p. 549)	144 (p. 549)	2/3 on tangent or all on spiral (p. 331)	16 (p. 551)	1-2 349
AASHTO Blue	30	250 (p. 169)	8 (p. 169)	8 (Assumed) (p. 169)	1:150 (pp. 175 & 360)	144 (pp. 175 & 360)	2/3 on tangent or all on spiral (p. 179)	16 (p. 338)	1-2 224
A	30	300 (p. 7-203.2)	12 (p. 7-202.2)	12 (p. 7-202.2)	1:167 (p. 7-202.7)	200 (p. 7-202.7)	2/3 on tangent (p. 7-202.7)	12 (p. 7-405.6) (p. 7-505.7)	2 (p. 7-301.2)
B	30	Refers to AASHTO Red and Blue Books. (p. 81)							2 (p. 42)
C	30	250 (p. 2-305.01)	8 (p. 2-310.01)	8 (p. 2-310.01)	1:140 (p. 3-310.06)	144 (p. 3-310.06)	2/3 on tangent Not provided criteria for spiral curve.	16 (p. 3-205.04)	1.56 (p. 3-310.06)
D	30	Refers to AASHTO Red and Blue Books (p. 2-310.06)					2/3 on tangent (p. 2-310.03)	16 (p. 7-515.04)	2 (p. 2-310.01A)
E	30	230 (p. 183)	6-10 (p. 67)	10 (p. 67)	1:112 (p. 188)	67 (p. 188)	(RGS-001-02) Full at P.C. or P.T. or S.C. or C.S.	15 (p. 192)	2 (p. 68a)
F	30	272 (1-4-79) (p. 6-25)	6 (p. 6-26)	6 (p. 6-26)	1:115 (p. 5-16) Table 3-2, 3-2A	110 (p. 5-16) Tables 3-2, 3-2A	70% on tangent or all on spiral plus tangent Runout Distance (p. 5-16)	16 (p. 3-13)	2 (p. 6-26)
G	30	250 Tab. 401-1 (2-78)	8.3 Tab. 602-1 (2-78)	8.3 (L&D) Tab. 602-1	1:125	166	Spiral (5-1-64)	16 (5-1-64)	3/16"/Ft. (2-78) (L&D E 501-8)
H	30	250 (p. 2.2.05)	8 (p. 2.3.10)	6 or 8 (p. 2.3.03)	1:150 (p. 2.1.01)	144 (p. 2.1.01)	2/3 on tangent (p. 2.1.01)	16 (p. 2.5.10)	2 (p. 2.1.08)
I	30	300 (p. 4-12)	5-9 (p. 4-91)	9 (p. 4-91)	1:119 (p. 4-91)	110 (p. 4-15)	2/3 on tangent (p. 4-17)	14 (p. 4-87)	1.5 (p. 4-81)
J	30	230 (p. 3-21.01)	10 (p. 3-23.04(2))	10 (p. 3-23.04)	1:133 (p. 3-23.04(3))	170 (p. 3-23.04(3))	70% on tangent (p. 3-23.04(2)B)	16 (p. 3-21.05(6))	2 (p. 3-23.01(1)D)
K	30	For speeds less than 35 MPH use AASHTO Blue Book. (E-D-10100)							1-Rigid Pav't. 1.5-Flex. Pav't. (E-D-11331d 4/9)
Canada	30	230 (p. 169)	8 (p. 118)	8 (p. 118)	1:104 (p. 119)	100 (p. 119 & 170)	2/3 on tangent or spir. (p. 33)	16 (p. 170)	2 (p. 60)

* Relative slope between profiles of the transitioning edge of pavement and the baseline profile

** Assuming a tangent precedes or follows a curve to the right (no spiral).

*** one lane, one way, no provision for passing with sufficient bus and semi-trailer trucks to govern design (AASHTO Case I, Condition C)

(p. 000) reference page in design manual

A-California, B-Florida, C-Illinois, D-Indiana, E-Kentucky, F-New York, G-Ohio, H-Pennsylvania, I-Texas, J-Washington, K-Wisconsin

Maximum Superelevation - This column illustrates the design agency's recommended policy for a maximum allowable cross slope rate at full superelevation. The range varies from 5%-12% with 8% dominating as the favorite.

Runoff - Superelevation runoff is the length of roadway needed to accomplish the change in cross slope from a normal crown section to a fully superelevated section, or vice versa.

Only three of the states reviewed give a specific runoff length for their 30 MPH design curve or use a method different from the AASHTO Red and Blue Books. All the others refer to the AASHTO books and specifically Table VII-13 (p. 360) in the Blue Book and Table J-5 (p. 549) in the Red Book. The two tables are identical. Three states even reproduce the table in their manuals. This AASHTO table gives a "Design Rate of Cross Slope Change for Curves at Intersections," which includes interchange ramps. It appears to the casual user that this table is suitable for any ramp width, but based on the narrative preceding Table VII-13 in the Blue Book (pp. 350 and 360), the table applies only to a pavement width of 12 feet. This assumption is further reinforced by the discussion of "Superelevation Runoff, Length Required," on pages 174-177 of the Blue Book. In this section, runoff lengths are established by giving the desirable maximum relative slope between profiles of the transitioning edge of pavement and the centerline. This method allows the designer to calculate a runoff length which considers both the pavement's change in cross section slope rate and its width. This method proposes for a 30 MPH curve a relative slope of 0.66% or an equivalent 1 in 150 ratio. Tables VII-13 and J-5 give values of .06 feet per foot rate of cross slope change per 100 feet for a 30 MPH design. This rate calculates to a 0.72% (1:139) relative slope for a 12' ramp pavement and 0.96% (1:104) for a 16' ramp pavement. From the AASHTO literature this latter rate appears to be undesirable (too steep), therefore it is concluded that Tables VII-13 and J-5 are intended only for 12-foot ramp pavements. If this conclusion is correct, these tables should be clarified since it appears that they are being misinterpreted by the design agencies. None of the agencies reviewed who are using these tables qualify them for use only with a 12-foot pavement width.

For comparative purposes in Table 1, Runoff has been divided into the three subcomponents of Relative Slope, Length and Treatment.

The relative slope ratios were calculated for most of the agencies. For the three states (states A, C & J) who did not refer to the AASHTO books, their relative slope ratios were 1:167, 1:140 and 1:133, respectively. It has been assumed that AASHTO's recommended maximum ratio is 1:150 for a 30 MPH design and does consider the ramp pavement width. For the Table 1 calculation, the same ratio has been assumed for the design agencies which refer to AASHTO, but individual calculated rates have been shown for the three agencies which include the AASHTO Table VII-13 (or J-5) in their manual. As Table 1 illustrates, these relative slope ratios are 1:104 (Canada), 1:112 (state E) and 1:119 (state I). Except for these latter three design agencies, all the others generally comply with the AASHTO recommended relative slope ratio, and states F (1:115) and G(1:125).

Runoff lengths were calculated from the combination of change in cross slope rates, pavement width and relative slope ratios. Lengths vary drastically from a minimum of 67 feet in state E to a maximum of 200 feet in state A. State A's length would probably even be considerably longer if they used a ramp width more in line with the other agencies. (They presently use only a 12-foot width). Runoff length itself has too many variables (see above) to use it as a comparative tool by itself.

The ramp runoff treatment comparison shows that almost all the design agencies prefer to transition from normal crown to full superelevation either on a spiral or by placing approximately 2/3 of the runoff length on the tangent preceding (or following) the curve and approximately 1/3 within the curve. Only one state manual (state E) calls for all the runoff to take place on the tangent but only when there is no spiral.

Lane Width - Assuming a one lane, one way operation, with no provision for passing, and having sufficient bus and semitrailer truck vehicles to govern design (AASHTO's Case I, Condition C), pavement widths vary from 12'-16', with the overwhelming favorite being 16' as recommended by AASHTO.

Normal Crown - Assuming a high type pavement (for high traffic volumes and relatively high running speeds) pavement cross slope rates on tangents range from 1%-

2% with most agencies being close to the upper (2%) range. The objective is to maintain as near to level a surface as possible for driving comfort while also attempting to drain the pavement surface of water quickly in order to minimize hydroplaning and skidding.

SPIRALS

The AASHTO Red Book encourages spirals on freeways between substantially different radii circular curves and between tangents and circular curves (p. 330). It also recommends spirals for high speed arterial streets and loop ramps (p. 545).

The principal advantages:

1. Provides a natural path for drivers.

2. Provides a transition distance for superelevation runoff.

3. Facilitates roadway width changes on curves.

4. Enhances appearance by avoiding noticeable breaks in horizontal and vertical alignment.

Table 2 presents a summary of individual manual policies on the use of spirals on freeways and ramps. Three categories have been established to illustrate the various policies. They are:

1. Specific Criteria Available - This means that the agency specifies when a spiral should be used and provides the appropriate length. Almost half of the agencies provide specific criteria for freeways, but only two of the fourteen are specific on ramps.

2. Designer's Judgment - This means that the design agency lets the designers decide whether the conditions warrant the use of a spiral transition. Only three agencies do this for freeways, and almost half of the fourteen allow this judgment on ramps.

3. Not Standard Practice - This means that the agency does not normally use spirals. Surprisingly six of the design agencies do not normally use spirals on the freeways and half of the fourteen do not normally use them on ramps.

It can readily be seen from Table 2 and the above descriptions that many design agencies do not consider that the advantages of spirals noted by AASHTO are worth the bother of

TABLE 2

POLICY ON USE OF SPIRALS

DESIGN AGENCY	Specific Criteria Available		Designers Judgment		Not Std. Practice		Design Manual Page
	Freeway	Ramp	Freeway	Ramp	Freeway	Ramp	
AASHTO Red	X			X			330, 545
AASHTO Blue	X	X					169, 172 327 and 532
A					X	X	7-203.9
B			X	X	X	X	28 and 32
C					X	X	
D					X	X	2-310.03
E	X			X			70, 71, 87
F	X			X			3-10, 3-10A
G	X	X					L&D 5/1/64
H	X					X	2.2.10 and 2.6.30
I					X	X	Dept. policy. No ref. page.
J					X	X	Fig. 3-23.04(2)
K			X	X			E-D-11331e
Canada			X	X			34, 35

incorporating them into their designs, and especially on ramps where transitioning of running speeds is most predominant.

PROFILE GRADES (MAXIMUM AND MINIMUM)

The AASHTO Red Book recommends the following principal guidelines:

1. Freeways (pages 337-344)

    a. Use maximum grades infrequently. Grades vary depending on design speeds and topography.

    b. Maximum grades are less objectionable on lengths less than 500 feet and for one-way downgrades.

    c. In extreme cases, 1% steeper than the recommended maximum may be used.

    d. Minimum grade criteria is usually controlled by drainage requirements.

2. Ramps (page 546)

    a. Desirable maximums are 6%, and only 5% where snow and ice are expected.

    b. Where there are many heavy trucks, use 4% maximum upgrades.

    c. May use 10% in exceptional cases such as low volume minor ramps.

    d. Steep grades are not as objectionable if the gradient aids acceleration or deceleration.

    e. High-speed ramps or those joining high-speed freeways should use flatter than maximum grades.

    f. Combination sharp horizontal curves on downgrades should be flatter than similar upgrade conditions since the downgrade situation makes steering difficult.

    g. Minimum grade criteria is usually controlled by drainage requirements.

Table 3 illustrates profile grade criteria of the fourteen various design agencies. For comparative purposes, a 60 MPH freeway was selected since freeway grades vary with design speed. Ramp grade criteria are not dependent on design speed.

60 MPH Freeways

Maximum grades range from 3%-6%, primarily depending upon the topography of the area. Where the terrain is relatively flat, maximum grades of 3% are expected. In hilly to mountainous terrain, 6 percent grades are normally tolerated. All design agencies emphasize using the flattest grades practical for the area.

Minimum grade ranges of zero to .75% are shown. The flat grade is usually avoided whenever possible since pavement drainage problems, (causing hydroplaning) can result. The upper limit (.75%) is desirable on curbed roadway sections in order to minimize the spread of drainage along the curbs onto the travel lanes. Table 3 illustrates considerable profile grade design uniformity for freeways.

Ramps

Maximum grades range from 4% to 10%, depending on topography, winter weather conditions, truck volumes, total traffic volumes, traffic direction, horizontal curvature and design speed. Most of the design agencies prefer 4% to 5% maximums and tolerate 6% to 8%. Grades as steep as 10% are noted by AASHTO, but only for extreme situations.

Table 3 illustrates considerable uniformity in design for maximum ramp grades between the agencies surveyed.

Specific minimum grade criteria for ramps could not be found in the design manuals of six of the fourteen agencies. The ranges found in the other manuals were the same as those for freeways (zero-.75%) and for the same reasons. It can safely be assumed that the missing criteria is intended to be similar to that used for freeways.

STOPPING SIGHT DISTANCE

The AASHTO Red Book (page 324) offers the highway designer desirable and minimum stopping sight distances for various design speeds ranging from 30 MPH to 70 MPH. The AASHTO Blue Book (p. 136) gives the same minimum distances as the Red Book, while the Supplemental AASHTO booklet entitled, "A Policy on Design Standards for Stopping Sight Distance," 1971 gives the same desirable distances. This booklet recommends that the Blue Book graphs, tables, etc., be revised by their individual owners for conformance to the recommended desirable distances.

Table 4 illustrates comparative 30, 50 and 70 MPH stopping sight distance criteria for the fourteen design agencies

TABLE 3

MAXIMUM-MINIMUM GRADES

DESIGN AGENCY	60 MPH Freeways		Ramps		Design Manual Page
	Maximum (%)	Minimum (%)	Maximum (%)	Minimum (%)	
AASHTO Red	3-4-6*	.35-.50**	5-6-10***	.35-.50**	338 and 546
AASHTO Blue	3-4-6*	.35-.50**	4-6-10***	.35-.50**	194, 195, 535, 536
A	3-6*	0-.12-.50	***** 30-50 MPH Vert. Curves	.12-.50	7-204.3 and 7-505.3
B	4	Refers to Red and Blue Books			33
C	4 Urban +4 to -6 Rural	0.35**	4, -6	****	2-615.01, 3-310.07
D	3	0.50	Refers to Red and Blue Books		2-325.01, 2-315.02
E	3-4-6*	0.3 Fill 0.5 Excavation	****	0.3 Fill Sec. 0.5 Excavation	91
F	4	0-0.5	5-8	****	2-3, 5-18, 6-26
G	4	.24	4-6	****	2-78, 820.02
H	6	.50-.75**	****	.50-.75**	2.1.04, 2.2.06
I	3-4	0-.35**	4	0-.35**	4-19 and 4-81
J	3-5	0.35	****	****	3-22.02(2)
K	3-5	0.3-0.5	4-6	****	E-D-10200 4/9 E-D-11331e, 3/7 Table 11331e-1
Canada	4	0.05-0.5	5-7	****	20, 21, 170

* Flat - Rolling - Hilly
** Open Shoulders - Curbed
*** Desirable - Acceptable - Extreme
**** Could not find specific criteria in the design manual
***** Generally try for 50mph on first vertical curve beyond exit nose.

TABLE 4

RELATION OF STOPPING SIGHT DISTANCE TO DESIGN SPEED

DESIGN AGENCY	30 MPH Minimum (Ft.)	30 MPH Desirable (Ft.)	50 MPH Minimum (Ft.)	50 MPH Desirable (Ft.)	70 MPH Minimum (Ft.)	70 MPH Desirable (Ft.)	Design Manual Page
AASHTO Red	200	200	350	450	600	850	324
AASHTO Blue	200	200	350	450	600	850	136
A	200	*	350	*	750	*	7-201.1
B	200	200	350	450	600	850	40
C	200	200	350	450	600	850	3-310.06a 3-310.07
D	200	200***	350	450***	600	850***	2-301.06A
E	200	200	350	450	600	850	50
F	200	200	350	450	600	850	2-3, 5, and 6-25
G	200	200	350	450	600	850	601.33 2-78
H	200	200	350	450	600	850	2.4.01
I	200	200	350	450	600	850	4-10
J	200	240	350	475	600	850	3-22.01(5)
K	200	200	350	450	600	850	E-D-11350 E-D-11352 E-D-10100
Canada	200	*	350	*	475**	*	170

* Could not find specific criteria in the design manual

** Stopping sight distance for 60 MPH

*** Road Memorandum No.83, Subject: Desirable Stopping Sight Distance (1977) reviewed. There is almost complete conformity with the AASHTO minimum and desirable criteria. None of the agencies recommend less than AASHTO.

ACCELERATION AND DECELERATION LANE LENGTHS

The AASHTO Red and Blue Books were found to differ considerably in the method of measuring the transition lengths of acceleration and deceleration lanes. In essence, the difference is that the Red Book provides sufficient length to change speeds entirely on the speed change lanes, while the Blue Book permits the speed changes to partially take place on the through lanes. The transition lengths shown in the various tables included in the two AASHTO books are comparable.

The Red Book (p. 555) measures the acceleration length from the P.T. of the last ramp curve to the last 12 foot width point on the speed change lane (see Figure 1). The Blue Book (p. 356) measures from the P.T. of the last ramp curve to the end of the taper of the speed change lane (Figure 1).

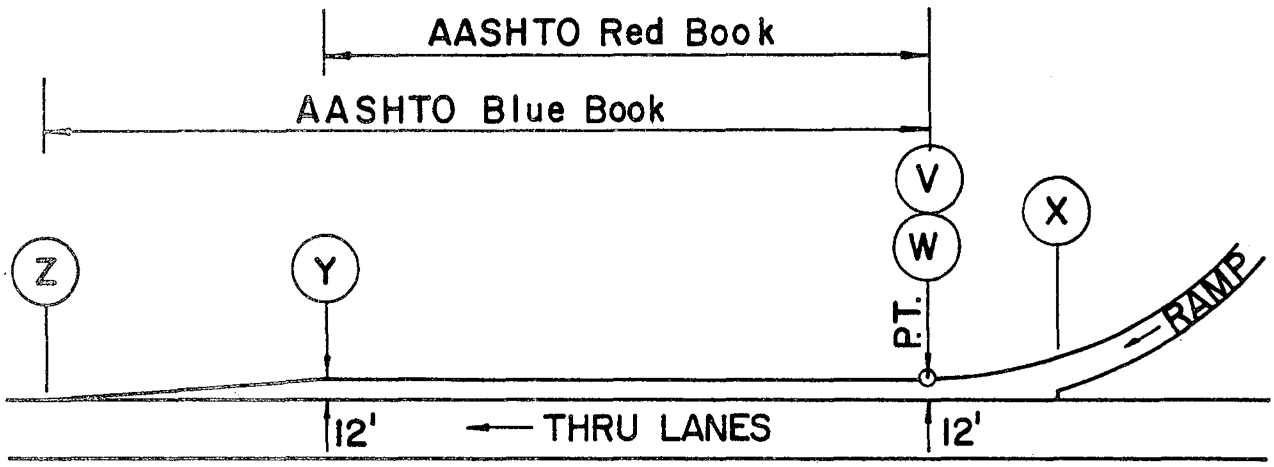
The Red Book (p. 558) measures the deceleration length from the first 12 foot width point of the speed change lane fo the P.C. of the first ramp curve (see Figure 2). The Blue Book (p. 353) measures from the beginning of the speed change lane taper to the P.C. of the first ramp curve (Figure 2).

There seems to be some confusion amongst the states as to which AASHTO book to use as a design criteria guide for speed change lane lengths. Most do not comply with the Red Book criteria and apparently are unaware of the FHWA Notice N-5040.14 of September 2, 1975, which states that the 1973 Red Book is to be used when its policy differs from the 1965 Blue Book. It also could not be determined for some of the states reviewed which method they use to measure their acceleration and deceleration distances, the Red Book's or the Blue Book's.

Acceleration lanes

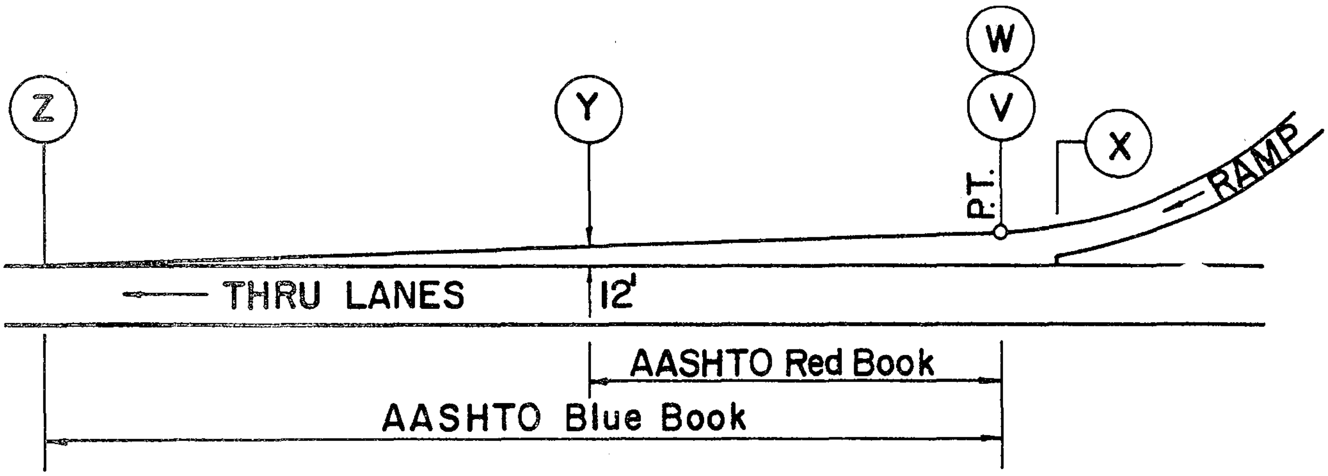
Based upon an example ramp design speed of 30 MPH merging onto a freeway design speed of 70 MPH, the AASHTO Blue Book recommends a minimum acceleration length of 1330 feet. Table 5 illustrates that the minimum lengths recommended by the various states using the Blue Book method of measurement range from a low of 1,000 feet (state G) to a high of 1,630 feet (states B and E).

The AASHTO Red Book, based on the above design speeds, also recommends a minimum acceleration length of 1330 feet. Table 5 illustrates that the minimum lengths recommended by the various states using the Red Book method of measurement



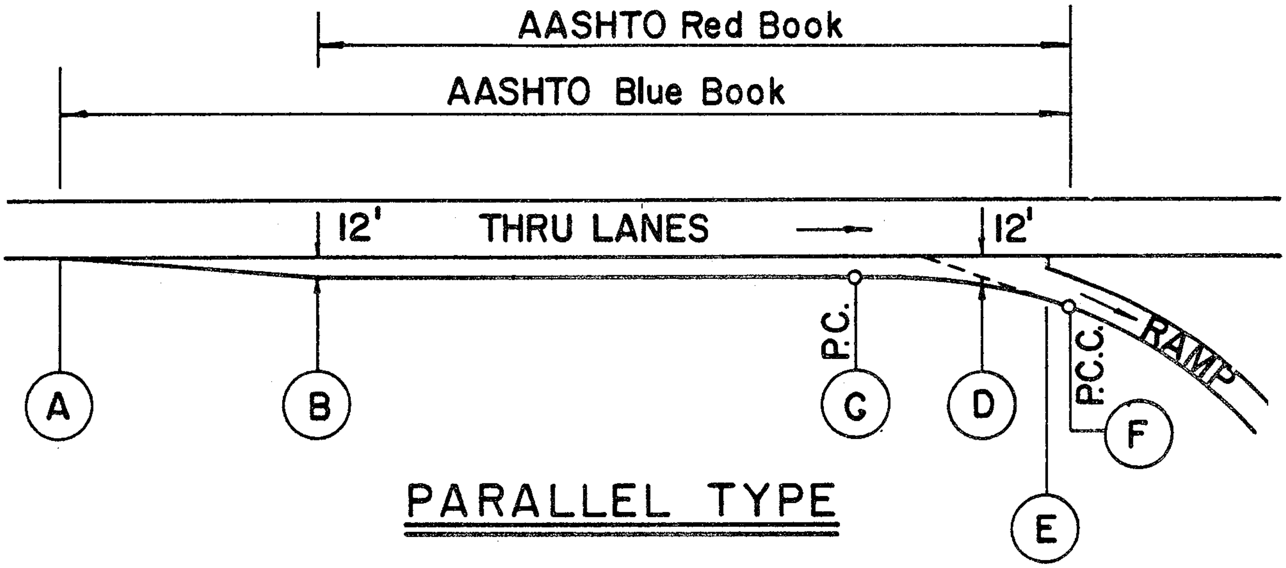
PARALLEL TYPE

V = Begin Acceleration Lane
W = Last P.T.
X = Nose
Y = Last 12' Point
Z = End of Taper or End of Pavement



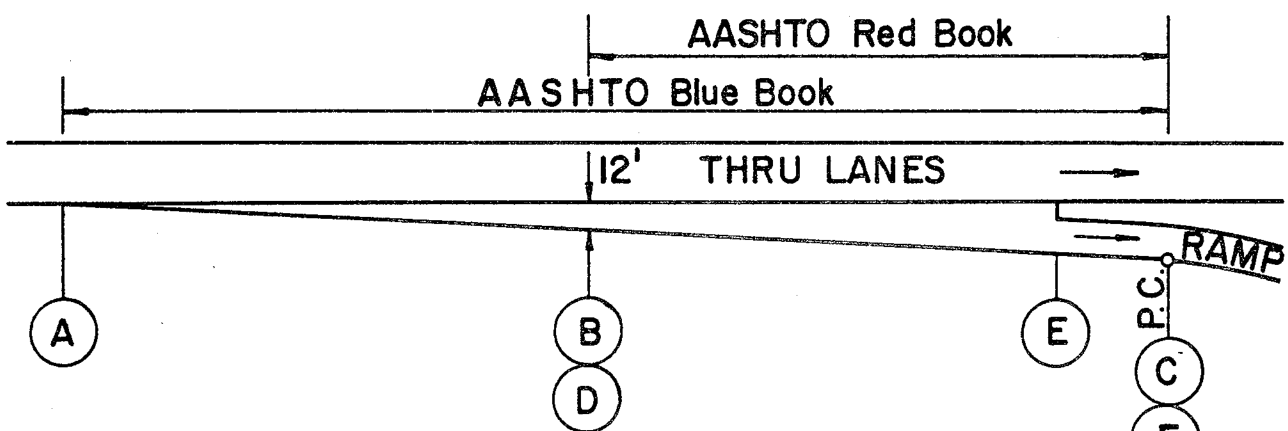
TAPER TYPE

FIGURE 1
ACCELERATION LANE LENGTHS



PARALLEL TYPE

A = Beginning of Taper or Beginning of Pav't.
B = First 12' or 14' Point
C = First P.C.
D = Theoretical 12' Point
E = Nose
F = End of Deceleration Lane



TAPER TYPE

FIGURE 2
DECELERATION LANE LENGTHS

range from a low of 460 feet (state F) to a high of 1,330 feet (states B and E).

Table 5 shows that there is little uniformity in either the acceleration length or the method of measurement used by the various design agencies. Since the 1973 Red Book is to be followed whenever there is a conflict with the 1965 Blue Book, there are some serious criteria differences between the Red Book and all the other design agencies except states B and E. States B and E are the only agencies which appear to conform to the Red Book.

Note that all the design agencies use a taper type acceleration lane, except state B and D, for the example design speeds. State B also uses a taper type when the entrance curve speed is 50 MPH or greater.

Deceleration lanes

Based upon an example freeway design speed of 70 MPH and a ramp speed of 30 MPH, the AASHTO Blue Book recommends a minimum deceleration distance of 510 feet including the taper. Table 6 illustrates that the minimum lengths recommended by the various agencies for the Blue Book method of measurement range from a low of 480 feet (state J) to a high of 1,175 feet (state H).

The AASHTO Red Book, based on the above design speeds, also recommends a minimum deceleration distance of 510 feet excluding the taper. Table 6 illustrates that the minimum lengths recommended by the various agencies for the Red Book method of measurement range from a low of zero feet (state K) to a high of 1,000 feet (state D).

Table 6 shows that there is little uniformity in either the deceleration length or method of measurement used by the various design agencies reviewed. Since the 1973 Red Book is to be followed whenever there is a conflict with the 1965 Blue Book, there are some criteria differences between the Red Book and five of the other fourteen design agencies reviewed. These five agencies do not provide the minimum deceleration length recommended by the Red Book. Although the differences here are not as drastic as for the acceleration lanes, a high degree of non-conformity is still evident.

Excluding the AASHTO books, seven design agencies use a taper type deceleration lane and six use parallel types for the example design speeds. State B also uses a taper type when the design speed of the exit curve is 50 MPH or greater.

TABLE 5

MINIMUM ACCELERATION LANE DIMENSIONS
FOR 30 MPH RAMP MERGING ONTO 70 MPH FREEWAY
(For Entrance grades less than 3%)

DESIGN AGENCY	Distances in feet from Point Z (See Figure 1) Z	Y	X	W	V	Accel Dist. (Blue Book) V to Z	Accel Dist. (Red Book) V to Y	Type Accel Lane	Design Manual Page
AASHTO Red	0	600		1930	1930		1330*	Taper	555
	0	300		1630	1630		1330*	Parallel	555
AASHTO Blue	0	600		1330	1330	1330*		Taper	356
	0	300		1330	1330	1330*		Parallel	356
A	**** 0	600	1067	900	1067	1067*	467	Taper	7-505
B	0	300			1630	1630	1330*	Parallel	86
*** C	0	550	950	1250	1250	** 1250	** 700	Taper	3-310.0
D	0	600	1200	1200	1350	* 1350	750	Parallel	M-V-4, pg. 40
E	0	300	1100	1630	1630	1630	1330*	Parallel (Loop) Taper (Dir.)	Std. Entrance Ramp
F	0	690	1150	1150	1350	** 1150	** 460	Taper	6-39
G	0	480	480	960	1000	* 1000	520	Taper	Fig. 501-2 Class II 2-78
H	**** 0	600	900	1100	1425	1425	825*	Taper	2.109A
I	0	600	1050	1050	1290	** 1290	** 690	Taper	4-85, 4-87
J	0	500	1300	1300	1300	1300*	800	Taper	3-25.05
K	0	600	1000	1550	1550	1550*	950	Taper	E-D-10100 Sheet 6 of 10
Canada	0	537	850	850	850	*** 850	*** 313	Taper	E4.3B

* Design Agency's method of measuring acceleration distance
** Cannot determine which method design agency uses to measure acceleration distance
*** Based on 40 MPH to 70 MPH
**** Theoretical end of taper.

V = Begin Acceleration Lane
W = Last P.T.
X = Nose
Y = Last 12' Point
Z = End of Taper or End of Pavement

TABLE 6

MINIMUM DECELERATION LANE DIMENSIONS
FOR 70 MPH FREEWAY DIVERGING ONTO 30 MPH RAMP
(For Exit grades less than 3%)

DESIGN AGENCY	Distances in feet from Point A (See Figure 2) A	B	C	D	E	F	Decel Dist. (Blue Book) A to F	Decel Dist. (Red Book) B(D)-F	Type Decel Lane	Design Manual Page
AASHTO Red	0	150	660			660		510*	Taper	558
	0	200	710		710	710		510*	Parallel	558
AASHTO Blue	0	170	510			510	510*		Taper	353
	0	200	510			510	510*		Parallel	353
A	0	142	613	142	413	613	613	471*	Taper	7-505.6
B	0	200			710	710	710	510*	Parallel	85
C	0	220	760	220	660	760	760**	540**	Taper	Design Communique I-74-6
D	0	100	309.09	500	1100	1100	** 1100	** 1000	Parallel	M-V-4
E	0	180.40	741.64	180.40	541.20	741.64	741.64	561.24*	Parallel Loop Taper (Dir.)	Std. Exit Ramp
F	0	172		172	485	485	485	300	Taper	6-37
G	0	100	540	670	800	800	** 800	** 700	Parallel	Fig. 501-1 (2-78) (2-78)
*** H	0	200	400	500	830	1175	1175	(975) 675*	Parallel	2.109B
I	0	315	0	315	655	840	840	525*	Taper	4-85, 4-87
J	0	180	480	180	600	480	480*	300	Taper	3-25.05(5)A
K	0	640	640	640	-	640	640	0	Taper (1)	Exit Ramp E-D-10100
	0	225	615	225	288	615	615	390**	Taper (2)	7 of 10
Canada	0	150		150	550	550	550**	400**	Parallel	E4.3(A)

A - Beginning of Taper or Beginning of Pavement
B - First 12' or 14' Point
C - First P.C.
D - Theoretical 12' Point
E - Nose
F - End of Deceleration Lane

*Design Agency's method of measuring deceleration distance

**Cannot determine which method Design Agency uses to measure deceleration distance

***
State H - First 12' Point to end of Decel
(975') (AASHTO Red Book Parallel Type)
675' - Theoretical 12' Point to end of Decel
(State H & AASHTO Red Book Taper Type)

TWO LANE ENTRANCE AND EXIT TERMINALS

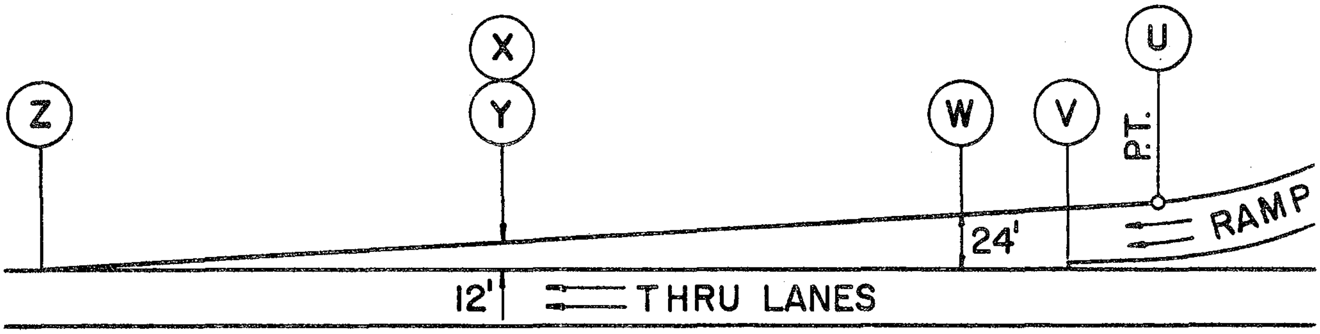
Figures 3 and 4 and Tables 7 and 8 were prepared to compare the lengths and types of two lane entrance and exit terminals used by the fourteen design agencies reviewed. Some of the agencies reviewed do not show any specific geometric layout for two lane terminals in their design manuals. The tables were prepared based on a two lane freeway width both upstream and downstream from the ramp terminals, i.e., through lanes were not dropped or added. The tables illustrate little uniformity in the lengths used by the various agencies reviewed. Less than half of those states which have criteria comply with the Red Book standards.

Two lane entrance terminals

Figure 3 and Table 7 illustrate that from the last 24 foot width point of the ramp to the end of the taper, the AASHTO Red Book recommends a desirable minimum distance of 2600 feet for the parallel type and 3200 feet for the taper type. The AASHTO Blue Book recommends only 1200 feet for these same limits on a taper type facility. The Blue Book does not show a parallel type terminal. The corresponding distances for the design agencies which have specific criteria range from a minimum of 2200 feet (state A) to a maximum of 3,500 feet (state H), disregarding the type terminal. Only one state (state C) uses a taper type entrance terminal while six recommended parallel type facilities. No specific layout could be found in the design manuals of three of the design agencies reviewed.

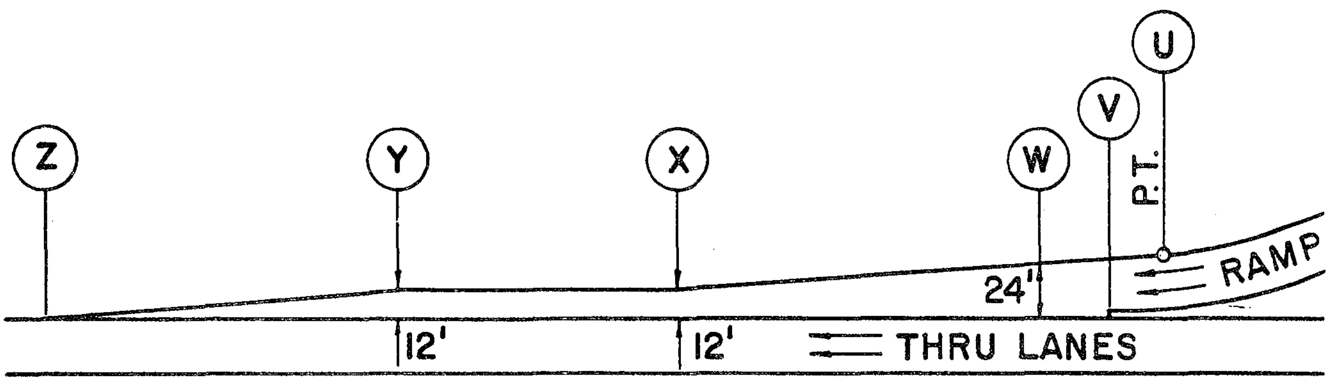
Two lane exit terminals

Figure 4 and Table 8 illustrate that from the beginning of the ramp taper to the first 24' width point of the ramp, the AASHTO Red Book recommends a desirable minimum distance of 2100 feet for the parallel type and 1972 feet for the taper type. The AASHTO Blue Book recommends a parallel additional lane where exceptionally heavy volumes require a two lane exit ramp, but it does not show specific dimensions. The corresponding distances for the design agencies which have specific criteria range from a minimum of 1,145 feet (State F) to a maximum of 3,200 feet (State G), disregarding the type terminal. Only one of the states (State H) uses a parallel type exit terminal. No specific geometric layout could be found in the design manuals of three of the design agencies reviewed.



TAPER TYPE

U = Last Ramp P.T.
V = Nose
W = Last 24' Point
X = First 12' Point
Y = Last 12' Point
Z = End of Taper or End of Pavement



PARALLEL TYPE

FIGURE 3
TWO LANE ENTRANCE TERMINALS

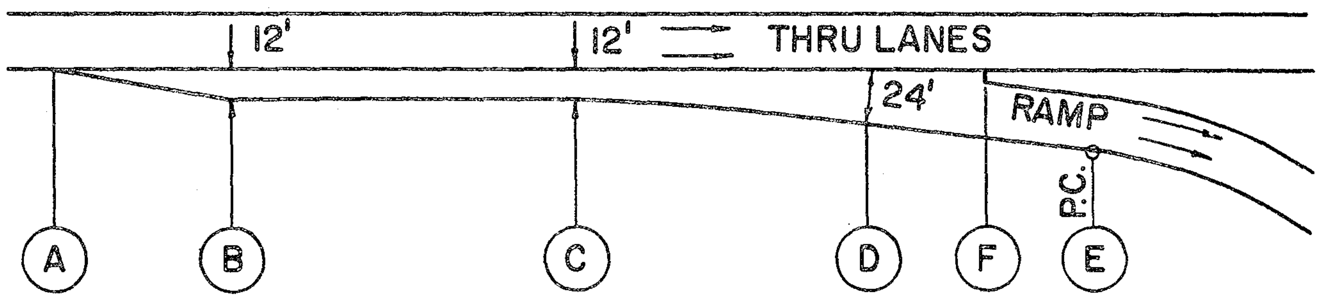
TABLE 7

TWO LANE ENTRANCE TERMINALS

DESIGN AGENCY	Distances in feet from Point Z (See Figure 3)						Type Entrance Terminal	Design Manual Page
	Z	Y	X	W	V	U		
AASHTO Red	0 0	300 600	2300 2600	2600 3200		3400-5600* 3200	Parallel Taper	566 566
AASHTO Blue	0	600	600	1200			Taper	382
A	0	600	1600	2200	2667	2667	Parallel	7-5-5.6 7-505.7B
B	Refers to Red and Blue Books.							
C	0	600	2200	2800	3100	3200	Taper	From Ill.DOT Prel.Drawing
D	Refers to Red and Blue Books.							
E	No specific geometric layout in Design Manual							
F	0	690	2690	3380	3740	3740	Parallel	6-35
G	0	720	2720	3440	3980	3980	Parallel	Fig. 501-4 (2-78) Current practice
H	** 0	800	2800	3500	3710	3920	Parallel	2.1.09D
I	0	600	—	—	*** 2400		Parallel	4-89
J	0	300	1800	2400	3100		Parallel	3-25.05(3)
K	No specific geometric layout in Design Manual							
Canada	No specific geometric layout in Design Manual							

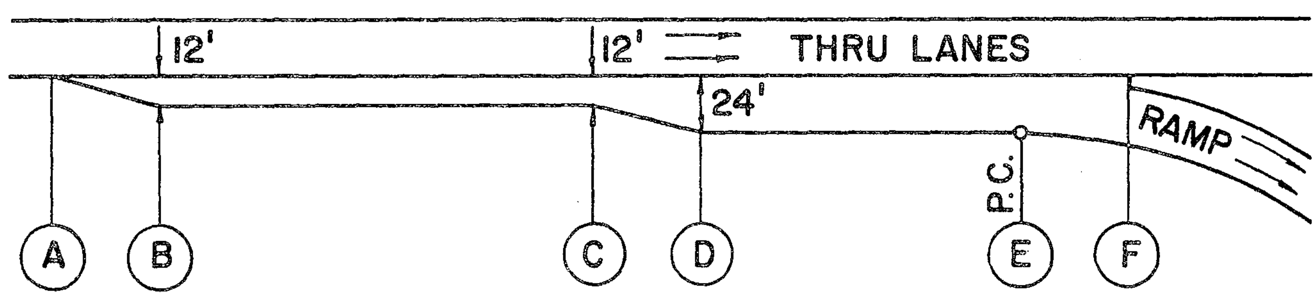
Z = End of Taper or Pavement
Y = Last 12' Point
X = First 12' Point
W = Last 24' Point
V = Nose
U = Last Ramp P.T.

*Depends on Traffic Volume
**State G is presently unofficially using a parallel type facility in most cases.
** Theoretical end of taper
*** One lane added downstream for a two lane entrance.



TAPER TYPE

A = Beginning of Taper or Beginning of Pav't.
B = First 12' Point
C = Theoretical or Last 12' Point
D = First 24' Point
E = First Ramp P.C.
F = Nose



PARALLEL TYPE

FIGURE 4
TWO LANE EXIT TERMINALS

TABLE 8

TWO LANE EXIT TERMINALS

DESIGN AGENCY	Distances in feet from Point A (See Figure 4)						Type Exit Terminal	Design Manual Page
	A	B	C	D	E	F		
AASHTO Red	0	300	1800	2100			Parallel	568
	0	300	1800	1972			Taper	568
AASHTO Blue	No specific lengths given						Parallel	344
A	0	142	1442	1584		1854	Taper	7-505.7B
B	Refers to Red and Blue Books.							
C	0	300	1800	2800	3410	3210	Taper	From Ill.DOT Prel. Drawing
D	Refers to Red and Blue Books.							
E	No specific geometric layout in Design Manual							
F	0	230	915	1145	1400	1145	Taper	6-35
G	0	350	2850	3200		3550	Taper	Figure 501-5
H	0	200	1500	1671	2346		Parallel	2-1.09C
I	0	300		1800			Taper	4-89
J	0	300	1800	2100		2900	Taper	3-25.05(6)
K	No specific geometric layout in Design Manual							
Canada	No specific geometric layout in Design Manual							

A = Beginning of Taper
B = First 12' Point
C = Theoretical or Last 12' Point
D = First 24' Point
E = First Ramp P.C.
F = Nose

RAMP PAVEMENT, PAVED SHOULDERS, AND STRUCTURE WIDTHS

According to the AASHTO Red Book (Table J-7), the width of single lane ramp pavements handling enough WB-50 vehicles (50 foot wheelbase semitrailer trucks) to govern design, should range from fifteen feet on tangent to twenty-three feet on curves whose radii are fifty feet or less. Most of the design agencies reviewed have similar criteria. States A and F use the narrowest pavement widths. State A uses a 12 foot width ramp pavement until the radius is less than 200 feet then switching to a wider pavement. State G also varies according to ramp curvature, changing from 16 feet to 18 feet when the radius becomes less than 200 feet.

Considerable variation in design criteria exists for the width of paved shoulders used in conjunction with ramps. Left side shoulder widths vary from two to five feet. Right side shoulder widths vary from four to ten feet. The Red Book recommends left shoulder widths of two feet to four feet and right shoulder widths of six to eight feet. All the agencies fall within this same left shoulder minimum criteria. Only state B and state K fail to meet the right shoulder minimum criteria of the Red Book.

AASHTO and most other agency's design criteria for structure widths recommend carrying the full roadway width (i.e., pavement plus paved shoulders) across the structure. Structure width is defined here to mean face of parapet to face of parapet.

Table 9 summarizes the recommended widths of ramp pavement, paved shoulders and structures of the various design agencies reviewed.

FRONTAGE ROADS

The AASHTO Red Book (Page 149) defines the uses of parallel frontage roads along freeways. Their basic purposes are:

1. For service to abutting freeway property and adjacent areas.

2. For control of access to the freeway.

3. For adding flexibility to the operation of a freeway, including their use as an alternate route for through traffic during emergency situations.

Practically all states consider frontage road usage based upon economic justifications, i.e., the total construction and right of way costs of the frontage road vs. the cost of acquisition of the landlocked property caused by the proposed highway construction.

TABLE 9

WIDTHS OF RAMP PAVEMENTS, PAVED SHOULDERS AND STRUCTURES

DESIGN AGENCY	*Pavement Width (Ft.)	Paved Shoulder Width (Ft.)		Structure Width (Ft.)
		Left	Right	
AASHTO Red	15-23 (p. 551)	2-4 (p. 551)	6-8 (p. 551)	**Full rdwy. width (p. 552)
AASHTO Blue	15-23 (p. 338)	4-10 (p. 341 & 540)	6-12 (p. 341 & 540)	**Full rdwy. width (p. 509 and 516)
A	12-18 (p. 7-405.6)	4 min (p. 7-302.1)	8 min. (p. 7-302.1)	12' min.&pavement= 24 min. (p. 7-211.1)
B	15-23 (p. 32 and GRT-01)	2 (GRT-01)	4-5 (GRT-01)	**Full rdwy. width (p. 55)
C	16-24 (p. 3-205.04)	4 (p. 3-310.05)	6 (p. 3-310.05)	10' wider than approach pavement (p. 4-005.07a)
D	Refers to Blue Book (p. 7-515.04)	Refers to Red and Blue Books	Refers to Red and Blue Books	Refers to Red and Blue Books
E	15-21 (p. 190) (p. 82)	4 (p. 190)	6 (p. 190)	See Bridge Guidance Manual
F	12-23 (p. 3-13)	3.5 (p. 3-55)	6.5 (p. 3-55)	No reference
G	16 (18 for R 200) (F501-8)	3 (Cl. II) (F501-2)	6 (Cl. II) (F501-2)	28'(5-1-64, Ramp typ. Section Sheet)
H	Refers to Blue Book (p. 2.6.02)	4 (p. 2.1.08A)	10 (p. 2.1.08A)	16 + pavement (p. 4.2.54)
I	14-23 (p. 4-1 & 4-87)	2 (p. 4-87)	6 (p. 4-87)	22 min. (p. 4-74)
J	14-23 (Fig. 3-21.05)	4 (p. 3-23. 01(1)D)	8 (p. 3-23. 01(1)D)	26 (p. 3-28.03(3))
K	15 (E-D-10100 2/10)	5 if R≥ 430' **** E-D-10100 2/10	5 if R≥ 430' **** E-D-10100 2/10	**Full rdwy. width (E-D-10200 1/9)
Canada	16-23 (p. 99)	5 (p. 170)	10 (p. 170)	**Full rdwy. width (p. 179)

*Pavement Width (Traveled Way) indicated pertains to one-lane, one-way operation with no provision for passing (AASHTO Case I, Condition C)

**Pavement and shoulders

***Could not find specific criteria in the Design Manual

**** 5' paved shoulder on high side or outside if Radius <430'. Barrier curb on low side or inside if Radius <430'.

State I appears to be somewhat unique in their policy on frontage roads. They encourage their use in almost all freeway designs because of the three reasons noted above and also because these parallel roadways can be used to carry and distribute some of the freeway traffic to help minimize overloading.

CLEARANCES AT UNDERPASSES

The AASHTO Red Book discusses lateral clearances for freeways on page 500 and for ramps on page 552. They indicate that lateral clearances should be designed to provide a clear roadside area for a width as great as practical for conditions along a specific section of highway. A clear width of 30 feet from the edge of the travel lane has been widely cited as a desirable freeway guide dimension, but no single value is appropriate. A minimum opening for freeways and ramps at overpass structures includes the median, (when practical) pavement and shoulders. Further restrictions may be required at times, especially where additional right of way acquisition is prohibitive. Most design agencies conform to this same policy.

The Red Book discusses vertical clearances for freeways on page 502. This same criteria is acceptable for all types of highways, including ramps. AASHTO recommends minimum vertical clearances of 14 feet to 16 feet with an additional minimum four inches clear for future resurfacing. All design agencies reviewed fell within this criteria. The upper limit of 16 feet (plus four inch minimum for resurfacing) is usually applied to Interstate Defense Highways. The Red Book further noted that where traffic is restricted to passenger vehicles only, the vertical clearance in no case will be less than 12.5 feet, but desirably 14 feet.

DISTANCE BETWEEN SUCCESSIVE RAMP TERMINALS

The distance required between successive ramp terminals is widely discussed but apparently not resolved sufficiently to permit generalizing into common guidelines. Only the Blue Book (pg. 529) and five states (states B, D, F, H and K) of the fourteen design agencies reviewed give specific distances for <u>each</u> of the four possible exit-entrance terminal combinations. Others cover only selected combinations.

Some agencies determine their minimum distances between successive terminals by speed change lane lengths, geometric considerations or weaving computations. Three agencies (state C, state J and Canada) use weaving distance computations to calculate the required distance between successive entrance and exit terminals. They give no criteria or references for the other three possible exit-entrance terminal combinations.

No criteria or references for any of the four combinations could be found in the manuals of states E or G.

Table 10 illustrates that there is considerable variation in criteria and lack of criteria among the design agencies reviewed. The following is a summary of these differences:

<u>Distance between successive exit terminals</u>

The AASHTO Red Book recommends a minimum of 1,000 feet between exits on a freeway and 800 feet between a freeway exit and an exit on a collector distributor or split in a ramp. Only five states meet this same criteria on freeways. They recommend similar values on the collector distributor and ramp splits except that state A requires a lesser minimum of 600 feet. Three other agencies give lesser minimum lengths and no criteria could be found in the manuals of five of the design agencies.

<u>Distance between successive exit-entrance terminals</u>

The AASHTO Red Book recommends a minimum of 500 feet between successive exit and entrance terminals. Only state H, recommending 750 feet, and states B & D meet this criteria. No other agency reviewed meets the Red Book recommendation. Three other agencies (Blue Book, state F and state K) require lesser minimum distances. For the remaining six agencies, no criteria could be found in their manuals.

<u>Distance between successive entrance terminals</u>

No specific criteria could be found in the AASHTO Red Book. The Blue Book recommends a minimum distance of 500 feet and desirable distance of 900 feet between entrance terminals for a 60-70 MPH freeway design. Only five states give specific criteria for this same design situation. State H exceeds the Blue Book criteria by recommending 1,000 feet on freeways and 600 feet on collector distributors and ramps. State F recommends a minimum of 1,350 feet. State B, D, and K give the same criteria as the Blue Book. State F further qualifies their criteria by saying that the desired speed change lane length may control the distance between successive entrances forcing the distance to a value greater than 1,350 feet. No specific criteria could be found for the remaining eight design agencies although state I says that the situation requires special design.

<u>Distance between successive entrance-exit terminals</u>

The AASHTO Red Book recommends that the minimum distance between these terminal types be governed by weaving

TABLE 10

MINIMUM DISTANCE BETWEEN
SUCCESSIVE RAMP TERMINALS

DESIGN AGENCY	Exit/Exit (Ft.)	Exit/ Entrance (Ft.)	Entrance/ Entrance (Ft.)	Entrance/ Exit (Ft.)	Design Manual Page
AASHTO Red	1000 (800)	500	*	1000 or Weaving**	579
AASHTO Blue	500 - 900	250 - 450	500 - 900	500-900 or Weaving ***	529
A	1000 (600)	*	*	1600 Min. or Weaving	7-505.7 9 and 1
B	Refers to Red and Blue Books				
C	*	*	*	Weaving	3-310-1
D	Refers to Red and Blue Books				
E	*	*	*	*	
**** F	Min.= 670' Des.=900' (600')	Min.=250' Des.=450'	Min.= 1350' Des.= Speed Change Lane Length	Min.=700' or Weaving	6-35, 6-41
G	*	*	*	*	
H	1000 (800)	750	1000 (600)	1000 or Weaving	2.1.09
I	1000 (800)	Governed by Geometrics	Requires special design	1000 w/aux. lane 1670 w/o aux. lane or Weaving	4-81, 86, 90 and App. D
J	*	*	*	Weaving	3-25.05(1 3-25.05(8
K	Refers to Chapter IX of AASHTO Blue Book				E-D-102005/9
Canada	*	*	*	Weaving	171

* Could not find specific criteria in the Design Manual
** When less than 1500' to 2000', connect lanes
*** When less than 2000', connect lanes
**** Based on Freeway Design Speed of 70 MPH
(000) Distance on Ramps and Collector-Distributor Roads

requirements, but desirably not less than 1,000 feet. Ten of the other design agencies also recommend that the distance be governed by weaving requirements. Seven of these ten agencies also give minimum lengths, of which five (states A, B, D, H & I) require minimums as long or longer than the 1,000 feet recommended by the Red Book. No specific criteria could be found in the design manuals of the two remaining agencies.

The AASHTO Red Book also recommends that the speed change lanes should be connected to provide a continuous lane if the entrance taper ending and exit taper beginning are less than 1,500 to 2,000 feet apart. State A has similar specific criteria (1,600 feet).

UNIFORMITY OF INTERCHANGE PATTERNS

The AASHTO Red Book notes on pages 537 and 583 that when a series of interchanges is being designed along a route, uniformity of pattern and its effect on operation of the freeway system should be considered. This is especially important in urban areas where interchanges are closely spaced and shorter distances are available to provide proper signing information. Dissimilar interchange patterns in these areas tend to confuse drivers, causing slow downs and erratic maneuvers. Left hand exits and entrances are especially undesirable according to most design guidelines. Whenever possible, the interchanges along a section of freeway should be similar in geometric layout, appearance, striping and signing. All states reviewed seem to agree with this uniformity principle.

AASHTO notes that the simplest and perhaps most common type interchange in urban areas is the diamond. Practically all states reviewed consider the diamond to be the best type for freeway to arterial (major/minor) interchanges. State I comments in their design manual (page 4-94) that diamonds are the most common interchange they use in urban areas since it requires less area. They also use them almost exclusively for major/minor crossings. A state I highway official estimates that over 90% of all their urban interchanges are diamond type and that they have provided very satisfactory operational and safety performances.

FREEWAY OVER VERSUS UNDER

The AASHTO Red Book does not address this specific topic. The AASHTO Blue Book (pp. 507-508) indicated the importance of detailed studies at interchanges to determine if the main road should be carried over or under the structure. Although the general topography and the line and grade of one or both of the intersecting highways are generally controlling factors, often several preliminary designs must be developed to determine if the freeway should pass over or under the sideroad. A good design must also consider such items as economics, interchange visibility, aesthetics, ramp profiles, earthwork, stage construction and drainage before a final interchange configuration can be selected.

The only other design agency of the fourteen reviewed which addresses this topic, is state F. State F's design manual cites a preference for a freeway to pass under the sideroad for the following reasons:

1. Increased awareness of the freeway driver that he is approching an interchange.

2. Ramp grades are usually such that a decelerating driver is on an upgrade and an accelerating driver is on a downgrade.

3. A depressed freeway is often less detrimental to adjacent properties.

An additional factor which should be considered in northern states where snow and ice are problems, is that bridge surfaces freeze before roadway surfaces. The designer may wish to favor the highway carrying the most traffic or the one requiring the most acceleration, deceleration, merging and yielding movements by placing it under the other roadway.

State B has verbally indicated that they almost always carry the freeway over a sideroad at an interchange in flat terrian. This reduces their right-of-way problems on the sideroad within the interchange area and provides relatively flat profile grades on their ramps.

IMPLICATIONS FOR SST DESIGN

Findings from review of the eleven state design manuals, Canada's design manual and the AASHTO Red and Blue Books tend to support the contract proposal theory that the manner in which individual design elements are fitted together is an area where improvements can be made. There are specific sections in the design manuals and AASHTO books for the design of ramp terminals, spirals, superelevation runoffs, profile grades, etc., based upon a desired design speed, but none of the design manuals reviewed require or suggest that the designer study a complete segment of roadway (e.g. a ramp) from beginning to end to insure that the combined horizontal, vertical and cross sectional elements provide proper smooth speed transition (SST) designs.

One state, state A, discusses an overview of a highway's horizontal alignment consistency. They say in part that "where it becomes necessary to introduce curvature of a lower standard that the design speed for the project, the design speed between successive curves shall not change more than 10 miles per hour." (p. 7-203.3) Although they may not intend this criteria to include ramps, the concept is similar to the proposed SST design, except that the SST will include all elements, not just horizontal curvature.

Based upon the findings of the design manual reviews, the following can be concluded:

1. Most of the agencies have adequate criteria developed for individual design elements.

2. Most of the states either rely heavily on the AASHTO Red and Blue Books or have developed their own criteria that is also based on these reference guides.

3. The SST design concept is just considered "good engineering practice" by all design agencies but it is not an item covered in any of the design manuals.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1980 -341-428/398

FEDERALLY COORDINATED PROGRAM (FCP) OF HIGHWAY RESEARCH AND DEVELOPMENT

The Offices of Research and Development (R&D) of the Federal Highway Administration (FHWA) are responsible for a broad program of staff and contract research and development and a Federal-aid program, conducted by or through the State highway transportation agencies, that includes the Highway Planning and Research (HP&R) program and the National Cooperative Highway Research Program (NCHRP) managed by the Transportation Research Board. The FCP is a carefully selected group of projects that uses research and development resources to obtain timely solutions to urgent national highway engineering problems.*

The diagonal double stripe on the cover of this report represents a highway and is color-coded to identify the FCP category that the report falls under. A red stripe is used for category 1, dark blue for category 2, light blue for category 3, brown for category 4, gray for category 5, green for categories 6 and 7, and an orange stripe identifies category 0.

FCP Category Descriptions

1. Improved Highway Design and Operation for Safety

Safety R&D addresses problems associated with the responsibilities of the FHWA under the Highway Safety Act and includes investigation of appropriate design standards, roadside hardware, signing, and physical and scientific data for the formulation of improved safety regulations.

2. Reduction of Traffic Congestion, and Improved Operational Efficiency

Traffic R&D is concerned with increasing the operational efficiency of existing highways by advancing technology, by improving designs for existing as well as new facilities, and by balancing the demand-capacity relationship through traffic management techniques such as bus and carpool preferential treatment, motorist information, and rerouting of traffic.

3. Environmental Considerations in Highway Design, Location, Construction, and Operation

Environmental R&D is directed toward identifying and evaluating highway elements that affect the quality of the human environment. The goals are reduction of adverse highway and traffic impacts, and protection and enhancement of the environment.

4. Improved Materials Utilization and Durability

Materials R&D is concerned with expanding the knowledge and technology of materials properties, using available natural materials, improving structural foundation materials, recycling highway materials, converting industrial wastes into useful highway products, developing extender or substitute materials for those in short supply, and developing more rapid and reliable testing procedures. The goals are lower highway construction costs and extended maintenance-free operation.

5. Improved Design to Reduce Costs, Extend Life Expectancy, and Insure Structural Safety

Structural R&D is concerned with furthering the latest technological advances in structural and hydraulic designs, fabrication processes, and construction techniques to provide safe, efficient highways at reasonable costs.

6. Improved Technology for Highway Construction

This category is concerned with the research, development, and implementation of highway construction technology to increase productivity, reduce energy consumption, conserve dwindling resources, and reduce costs while improving the quality and methods of construction.

7. Improved Technology for Highway Maintenance

This category addresses problems in preserving the Nation's highways and includes activities in physical maintenance, traffic services, management, and equipment. The goal is to maximize operational efficiency and safety to the traveling public while conserving resources.

0. Other New Studies

This category, not included in the seven-volume official statement of the FCP, is concerned with HP&R and NCHRP studies not specifically related to FCP projects. These studies involve R&D support of other FHWA program office research.

* The complete seven-volume official statement of the FCP is available from the National Technical Information Service, Springfield, Va. 22161. Single copies of the introductory volume are available without charge from Program Analysis (HRD-3), Offices of Research and Development, Federal Highway Administration, Washington, D.C. 20590.

B263

9