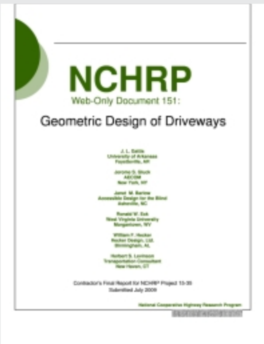
NCHRP

Web-Only Document 151:

Geometric Design of Driveways

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DETAILS

0 pages | null | PAPERBACK
ISBN 978-0-309-43095-1 | DOI 10.17226/17637

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NCHRP

Web-Only Document 151:

Geometric Design of Driveways

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Contractor's Final Report for NCHRP Project 15-35
Submitted July 2009

National Cooperative Highway Research Program
TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

ACKNOWLEDGMENT

This work was sponsored by the American Association of State Highway and Transportation Officials (AASHTO), in cooperation with the Federal Highway Administration, and was conducted in the National Cooperative Highway Research Program (NCHRP), which is administered by the Transportation Research Board (TRB) of the National Academies.

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ACKNOWLEDGMENTS

The research reported herein was performed under NCHRP Project 15-35 by the Department of Civil Engineering at the University of Arkansas (UA), prime contractor, and by AECOM, subcontractor. Subcontractors to AECOM include Accessible Design for the Blind, West Virginia University, Hecker Design, Ltd., and Herbert S. Levinson.

Dr. James L. Gattis, Professor of Civil Engineering at UA, was the Principal Investigator. Jerome S. Gluck of AECOM was the Co-Principal Investigator. Janet M. Barlow (Accessible Design for the Blind), Ronald W. Eck (West Virginia University), William F. Hecker (Hecker Design, Ltd.) and Herbert S. Levinson were special consultants for the project.

We wish to acknowledge the following individuals and companies whose generous cooperation contributed to the data collection and reduction effort for this research project.

Best Buy Here Pay Here, Fayetteville, AR

Frank Fletcher Chevrolet, Springdale, AR

McBride Distributing Company, Fayetteville, AR

McGaugh RV Center, Springdale, AR

Meineke Car Care Center, Broken Arrow, OK

Robert Mills, Wells Cargo, Inc., Waco, TX

and the transportation agencies of the following states and city: Arkansas, Connecticut, Florida, Illinois, Kansas, Maryland, Nebraska, New Jersey, New York, Ohio, South Carolina, South Dakota, Texas, Vermont, Virginia, Washington, and Springfield, Mo.

Also, we wish to acknowledge the following people who worked on the project.

Statistician - Lynnette Duncan

University of Arkansas, Mulitmedia Resource Center video support specialist - Sarah Moore

University of Arkansas technician, vehicle ground clearance measurement device - Dennis Rogers

University of Arkansas technicians, speed and elapsed time measurements - Scott Higginbotham, Mark Kuss

University of Arkansas students - Nick Braddy, Trent Ellis, Tymli Frierson, Jon Nolan, Ashly Pervis, Robert Reese, Ryan Reynolds, Krishna Timmasamudram-Reddy, Danny Xiao

ABSTRACT

Geometric Design of Driveways

Driveways are private roads that provide access (both ingress and egress) between a public way and abutting properties, and any facilities on those properties. The roadway engineers' focus is often on a part of the driveway, the area where the driveway intersects the public highway or street. Since these connections form the link or interface between public streets and highways and the activities they serve, driveways are an integral part of the roadway transportation system. There has been relatively little comprehensive research on or national guidance for the geometric design of driveways in recent decades. The objective of this project was to develop recommendations for geometric design of driveways that will be useful to state departments of transportation, local governments, and consultants in preparing driveway design standards and practices. The project included an extensive review of related literature, a survey of transportation agencies, a listing of almost 100 factors that can affect the design of a driveway, a list of needed research topics, and research on issues related to driveway vertical alignment. The project produced two documents, the project report and a driveway design guide.

EXECUTIVE SUMMARY

Geometric Design of Driveways

Driveways are private roads that provide access (both ingress and egress) between a public way and abutting properties, and any facilities on those properties. The roadway engineers' focus is often on a part of the driveway, the area where the driveway intersects the public highway or street. Since these connections form the link or interface between public streets and highways and the activities they serve, driveways are an integral part of the roadway transportation system. There has been relatively little comprehensive research on or national guidance for the geometric design of driveways in recent decades.

The objective of this project was to develop recommendations for geometric design of driveways that will be useful to state departments of transportation, local governments, and consultants in preparing driveway design standards and practices. To accomplish this, the project had been structured as follows.

1. The contractor reviewed research literature, obtained examples of transportation agency design documents, and conducted a survey of transportation agencies, in order to document the current state-of-practice and highlight research needs, and to identify topics and collect source materials for inclusion in the design guide.
2. After reviewing and considering a synthesis of the literature and documents, the project oversight panel selected topics for research.
3. The contractor conducted research related to the geometric design of driveways.
4. The contractor prepared a driveway design guide.

The recommendations were based on research findings, standard engineering practices, and engineering judgement. The intent of the recommendations is to provide safe and efficient travel by motorists, pedestrians, bicyclists, and transit users on and in proximity of the affected roadway.

The contractor reviewed almost 100 documents, received survey responses from one city and 16 state departments of transportation, and received input from 13 other entities. From this, a list of almost 100 factors that may affect the operation of a driveway was prepared. The contractor prepared a preliminary list of 14 driveway design-related topics that may warrant additional research, and then offered five of them to the project oversight panel for consideration. The project panel selected the following three areas for research.

1. Determine the crest and sag grade changes at which the underside of a static vehicle drags.
2. Determine what actual driveway profiles cause the undersides of vehicles to drag.

3. Assess the effects of angle changes (roadway cross slope – driveway grade) at the roadway-driveway interface and driveway grades on the speed and elapsed time of vehicles turning left and turning right into a driveway.

To determine the crest and sag grade changes at which the underside of a static vehicle drags, the contractor measured or obtained the profile dimensions of two automobiles, a pickup truck with a trailer, a Class A motor home (i.e., “diesel pusher”), and a beverage delivery truck. A geometric analysis was performed to determine at what crest and sag grade change the underside of the vehicle would drag the pavement surface. Since these analyses do not account for the effect of static load (weight of passengers or cargo) or dynamic load (vehicle bounce), maximum desirable grade changes will be less that those indicated by the calculations.

To determine what actual driveway profiles cause the undersides of vehicles to drag, the contractor surveyed the profiles of 31 driveways that displayed scrape marks near vertical crests and sags. From this, it was concluded that for driveways at which the passenger car design vehicle governed, the maximum vertical profile breakover without a vertical curve should be 10% at crests, and 9% at sags.

To assess the effects of angle changes (roadway cross slope – driveway grade) at the roadway-driveway interface and driveway grades on the speed and elapsed time of vehicles turning left and turning right into a driveway, the contractor made measurements at 12 commercial driveways on non-fringe suburban arterial multilane roadways with posted speeds of 40 and 45 mph. All of the roadways had either a raised median or a TWLTL. The data were collected at driveways with right turn entry radii ranging from 13 to 19.5 ft, and an entry lane width of about 13 feet. Over 1500 vehicle movements were recorded. Very few vehicles about to enter a driveway exceeded 20 mph at the locations at which speeds were measured. After the fronts of vehicles crossed the driveway threshold and were approaching a typical sidewalk location, average speeds for vehicles turning left into the driveway were around 10 mph. Vehicles that had turned right into the driveways were slightly slower, with average speeds around 7 mph. At the driveways studied, little differences in speed were found between driveways with flatter and with moderate grades (up to 9% grade, 10.5% breakover at the gutter). However, at the steeper sites (12.5% to 15.5% grade, 13.5% to 19% breakover at the gutter), speeds were slower and elapsed travel times greater. An analysis of the effects on motorists and pedestrians indicated that the greatest negative impact at the steeper sites would involve conflicts between vehicles turning into a driveway and oncoming through vehicles.

The quality of a design is determined by how well the design works after it is placed into operation. Therefore, the objective of geometric design is to identify the factors that affect the outcome, then choose component elements and combine them into a design in such a way that a desirable outcome is achieved, and avoidable undesirable outcomes are avoided, all the while being cognizant of economic constraints.

The design guide prepared reflected concerns of various groups that use the driveway, including bicyclists, motorists, pedestrians, and pedestrians with disabilities. The project report also included a number of suggested changes for the AASHTO Green Book.

CHAPTER 1
Introduction

1.1 BACKGROUND AND CONTEXT

Driveways are private roads that provide access (both ingress and egress) between a public way and abutting properties, and any facilities on those properties. Since they form the link or interface between public streets and highways and the activities they serve, driveways are an integral part of the roadway transportation system.

Driveways can be found along rural highways, suburban arterials, city streets, and alleys. They vary in size, activity, types of vehicles served, roadways accessed, development density, proximity to intersections, and pedestrian exposure. Where they are located and how well they are designed affect the safety and mobility of vehicles and pedestrians, and may impact the quality of roadside development. Driveways, especially busy commercial drives, can have a significant impact on the flow of traffic.

As Exhibit 1-1 shows, in the area where the roadway, the sidewalk and the driveway intersect, there are three distinct user groups with different and sometimes conflicting needs. Although members of all three groups typically want to make their trips as expeditiously as possible, the roadway user usually moves at a greater speed and, therefore, is often focused some distance ahead on the roadway. The sidewalk users (a heterogeneous group – such as pedestrians, pedestrians with disabilities, and those waiting for a bus or taxi – with different needs) move at a much slower pace, and are unprotected and vulnerable to vehicles. The driveway user typically has a speed and a path that can create conflicts with the other two user groups. Vehicles entering or leaving the driveway impact other motorists, as well as pedestrians and bicyclists crossing the driveway. Sometimes they affect traffic within the private development.

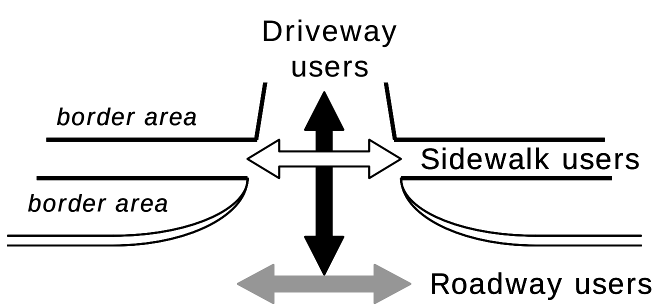


EXHIBIT 1-1 Driveway interactions

Interactions among the various user groups often occur within or near the border, the area between the roadway edge and the right-of-way line. (Roadway engineers often use the term driveway to denote that part of the driveway within or near the public right-of-way, the border area; that meaning was adopted for this study.) Therefore, the design of driveways in and near this area of interaction should consider the needs of each group of users. The designer should attempt to:

1. minimize impacts on other roadway users;
2. provide safe and convenient access for vehicles;
3. provide safe accessibility for pedestrians, including those that are disabled;
4. where bicyclists are present, accommodate interactions with bicycles; and
5. not adversely affect access to or the operation of public transit stops.

There has been relatively little comprehensive research on or national guidance for the geometric design of driveways since the American Association of State Highway Officials (AASHO) publication, *An Informational Guide for Preparing Private Driveway Regulations for Major Highways*, was published in 1959 (*AASHO, 1959*) . Since that time, roadway design, function, and volumes have changed as have vehicle design and many other aspects of the roadway environment. In addition, there has been a growing emphasis placed on managing access and on accommodating pedestrians. The U.S. Architectural and Transportation Barriers Compliance Board's *Draft Guidelines for Accessible Public Rights-of-Way* (*Access Board, 2005*) contain specific guidelines pertaining to pedestrian needs. There remains, however, an important need to better integrate vehicle and pedestrian design criteria.

1.2 RESEARCH OBJECTIVES AND SCOPE

The objective listed in the research problem statement was to develop recommendations for geometric design of driveways. The research problem statement went on to say that such recommendations will be useful to state departments of transportation and local governments in preparing driveway design standards and practices that consider standard engineering practice and accessibility needs and provide for safe and efficient travel by motorists, pedestrians, and bicyclists on the affected roadway.

To achieve the objective, the project was structured as follows.

1. The contractor reviewed research literature, obtained examples of transportation agency design documents, and conducted a survey of transportation agencies, in order to document the current state-of-practice and highlight research needs, and to identify topics and collect source materials for inclusion in the design guide.

2. After reviewing and considering a synthesis of the literature and documents, the project oversight panel selected topics for research.
3. The contractor conducted research related to the geometric design of driveways.
4. The contractor prepared a driveway design guide.

When roadway designers use the term “driveway”, they are often referring to just a part of a driveway, the area where the driveway intersects the public highway or street. For the most part, this project reflects the roadway designer definition of driveway, and does not consider the design of a driveway well within a private site, except as it affects the driveway intersection with the public roadway. During the initial stage of the project, the decision was made to limit the project scope to driveways that “look like driveways,” and exclude driveways “that look like streets.”

1.3 RESEARCH PLAN

The research project was structured into two basic phases. Phase 1 included Tasks 1 through 5, while Phase 2 included Tasks 6A, 6B, and 7.

In Task 1, the research team reviewed research literature and transportation agency documents that address the geometric design of driveways. Also, a survey instrument addressing the geometric design of driveways was prepared and sent to state and local transportation agencies. The responses were reviewed and summarized.

In Task 2, the team identified geometric elements and developed performance measures, based on the information from Task 1. Two detailed tables showing almost 100 factors that may need consideration during the geometric design of driveways were created. A list of 14 elements was prepared as preliminary candidates for additional research, along with associated design objectives and possible performance measures.

Task 3 involved an evaluation of the knowledge and practices associated with listed elements. These evaluations identified current practices, discussed the degree to which certain aspects had been studied and addressed, and stated outstanding questions.

In Task 4, the contractor suggested that for Phase 2 research activity, the project oversight panel consider and select from among a short list of five topics selected from among the preliminary list developed during Tasks 2 and 3.

During Task 5, the contractor submitted a draft report, and the project oversight panel discussed and selected the topic for Task 6A research.

Task 6A was devoted to conducting the selected research activities. Task 6B involved the preparation of a separate document, a guide for the geometric design of roadways.

Task 7 was the completion of the report, along with developing suggested revisions to the AASHTO (American Association of State Highway and Transportation Officials) Green Book (*AASHTO, 2004*).

CHAPTER 2
State of the Practice

Task 1 of the project called for a review of literature and current practices pertaining to the geometric design of driveways. Recognizing that multiple stakeholders are interested in driveway design, and that their input would expand the range of perspectives incorporated into this project, additional contacts were made to solicit their insight. As the project progressed, other possible sources of pertinent information were also pursued.

The material collected during Task 1 activities can be classified into the following sets.

1. Survey of Current Practices. Summary of the responses to the survey forms that were sent to departments of transportation.
2. Agency Documents. Passages, tables, or figures that either:
    a. represent one example of a widely-used practice, or
    b. show a somewhat unique practice, one not often found in the reviewed materials.
3. Literature Review. Reviews of articles, reports, and recommended practices related to the geometric design of driveways.
4. Additional Sources. In addition to the survey of transportation agencies and the review of literature, the research team expanded their search to include the following activities:
    a. requested input from organizations and groups that represent stakeholders (e.g., bicyclists, pedestrians, disabled pedestrians, public transit users) who may be affected by driveway designs and driveway traffic;
    b. searched for a source of pertinent vehicle dimensions that would be needed to examine and define limiting driveway profile attributes;
    c. performed a cursory examination of readily-available crash data, to gain insight into the nature and severity of driveway-related collisions.

This work served two purposes: it yielded insight into what topics were most in need of additional research, and it identified material to include in the subsequent product, a driveway design guide.

2.1 SURVEY OF CURRENT PRACTICES

In order to ascertain and document current driveway geometric design practices, state and local transportation agencies were contacted. The contact correspondence included the following statement.

> Please forward the enclosed questionnaire to the individual(s) in your department who is/are most familiar with your department's policies, procedures, and design documents for the geometric design of driveways. In addition, it may be appropriate

> to administer the survey to bike, pedestrian, and accessibility coordinators, or to traffic operations staff that deal with driveways. A given individual may not wish to respond to questions outside of their area of expertise. We envision receiving from 1 to 4 separate responses from an agency, or one combined response.

A heading on each page of the survey instrument reminded those taking the survey that their responses should reflect the current policies and practices of their agency.

One local (Springfield, Mo.) and the following 16 transportation agencies returned completed survey forms: Arkansas, Connecticut, Florida, Illinois, Kansas, Maryland, Nebraska, New Jersey, New York, Ohio, South Carolina, South Dakota, Texas, Vermont, Virginia, and Washington. About half of the surveys were completed by those who checked only “Roadway design” as their predominant work activity. Categories checked by other respondents included “Traffic operations” and “Research.” Since some respondents did not provide a response to some questions, the number of responses to a given question may not be equal to the number of agencies that responded to the survey.

Appendix A-1 contains the survey responses, and A-2 contains text, tables, and figures gleaned from agency documents. Appendix B contains additional materials submitted in response to certain survey questions.

2.2 LITERATURE REVIEW

The research team conducted a comprehensive literature review, and included material from over 90 research and design documents in the written review. These documents, listed in Exhibit 2-1, were focused on both motorized and non-motorized travel, and addressed topics such as user characteristics, safety, driveway entry geometry, driveway angle, setbacks to allow on-site queue storage, right-turn lanes, vertical alignment, and access location and spacing.

Two considerations strongly influenced the scope and selection of documents for this review. One, while driveways constitute an identifiable, unique component, separate and distinguishable from the traveled roadway, more than a few principles of roadway design are also at least in part applicable to driveways. Second, in the context of the full range of users – including those whose paths cross the driveway – information and considerations related to design for bicyclists, pedestrians, and pedestrians with disabilities may also be of interest to and need the consideration of the driveway designer. Therefore, the literature that is relevant to the geometric design of driveways can be broadly described as falling into one of two types:

EXHIBIT 2-1 List of reviewed documents

	Source				Emphasis:				Sources with a motor vehicle emphasis:							
	(First author or organization; abbreviated title)	Year	Research	Guidance	Bicyclist	Disabled pedestrian	Pedestrian	Public transit rider	Safety	Width & Entry (# lanes, radius, flare)	On-site storage setback	Angle	Decel., Rt.-turn Lane	Vertical alignment	Access design, controls	Access location, spacing
1	Access Board, *Accessible Sidewalks*	1999		x		x										
2	Access Board, *Accessible Rights-of-Way*	1999		x		x										
3	Access Board, *Bldg. True Community*	2001		x		x										
4	Access Board, *Draft Gd. Acces. Pub. ROW*	2005		x		x										
5	Ahmet, Right-In Right-Out	1998	x							x						
6	AASHO, *Info. Guide Pvt. Driveway Reg.*	1960		x						x		x		x		x
7	AASHTO, *Guide for Ped. Facilities*	2004		x			x									
8	AASHTO, Implementing SHSP website	2004	x		x											
9	Callender, *Time-Saver Stds*.	1966	x	x						x				x		
10	APA, *Plan. & Urban Design Stds.*	2006		x						x						
11	ASCE, *Residential Streets*	1990		x											x	
12	Azzeh, *Eval.Tech.Control Direct Access*	1975	x	x												
13	Boodlal, *Acc. Swalks. and St. Crossings*	?		x		x										
14	Box, "Dway. Acc. Study I" *Pub. Saf. Sys.*	1969	x													
15	Box, "Dway. II, Serv. Sta." *Pub. Saf. Sys.*	1969	x													
16	Box, "Dway. Study III, Des." *Pub. Saf. Sys.*	1969		x									x			
17	Box, "Analy. Traf. Impact 1" *Pub. Wks.*	1981		x									x		x	
18	Box, "Analy. Traf. Impact 2" *Pub. Wks.*	1981		x												x
19	Brubaker, "Ergo. Consid." *JIRRD Sup. 2*	1986	x			x										
20	Carter, *Intro. to Tran. Engr.*	1978		x						x		x		x		
21	Chicago, *Des. Stds. Manual*	1984		x						x		x				x
22	Clifton, "Role Ped-Veh Crash" ann. meet	2006	x				x									
23	Cooner, *Ops. & Safety Around Schools*	2004		x						x						x
24	DeCabooter, “Op Long Trucks” TRR 1249	1989	x							x						
25	Dixon, "Safe…Urb Rdside" NCHRP 612	2008		x						x						
26	Dye, *Review SD DOT Access Control*	2000		x											x	
27	Eck, "Low-Clear. Veh. at RR" TRR 1327	1991	x	x										x		x
28	Eck, "Rdwy. Stds. Low-Clear." TRR 1356	1992	x											x		
29	Ernst, *Mean Streets*	2004	x				x									
30	FHWA, *Synthesis Safety Research* Vol1	1982	x						x	x			x	x		x
31	FHWA, Course on Bicycle & Ped. Transp.	?	x		x											
32	Fitzpatrick, *Gdln. Bus Stops* TCRP 19	1996	x	x	x			x								
33	Fitzpatrick, TCRP 112 *Improve. Ped. Safety*	2006	x				x									
34	FL Sys. Plan., *Driveway Handbook*	2005	x	x						x				x	x	
35	Flora, *Access Mgmt. for Streets & Hwys*.	1982		x						x	x	x	x		x	x
36	French, "Devel. Design Veh." TRR 1847	2003	x											x		
37	Gattis, "School Bus Design" TRR 1658	1999	x							x						
38	Gattis, *Assess Need Access Control*	2005		x											x	
39	Gluck, NCHRP 420 *Impact. Acc. Mgmt.*	1999	x	x					x				x			x
40	Gluck, RRD 247 *Relation. Density & Acc.*	2000	x						x							x
41	Guth, "Veer. Blind Ped." *J. Vis. Impair.*	1995	x			x										
42	Guth, "Perception" *Found. of O.& M.* 2ed	1997	x			x										
43	Guth, "Blind Roundabout" *Human Factors*	2005	x			x										x
44	Hadi, "Spd. Diff. Rt-T. Decel." TRR 1847	2003	x													
45	Harkey, *Beta Test Ped. Crash Analy.*	2001	x				x									
46	Hasan, "Gdln. Rt-Turn Treatments" KSU	1996	x	x									x			
47	Hill, *Orient. & Mob. Tech*	1976		x		x										

Source (First author or organization; abbreviated title)	Year	Research	Guidance	Emphasis: Bicyclist	Disabled pedestrian	Pedestrian	Public transit rider	Sources with a motor vehicle emphasis: Safety	Width & Entry (# lanes, radius, flare)	On-site storage setback	Angle	Decel., Rt.-turn Lane	Vertical alignment	Access design, controls	Access location, spacing
48 Hodgson, *Prelim. Assess. Effects A. M.*	1999	x							x						
49 Homburger, *Fund. of Traf. Engr.*	1996		x						x		x				x
50 Hunter, *Ped. & Bicycle Crash Types*	1995	x		x											
51 ICC/ANSI A117.1-1998	1998		x		x										
52 ICC CABO A117.1-1992, *Commentary*	2002		x		x										
53 ICC/ANSI A117.1-2003	2003		x		x										
54 Iqbal, *Estab. Dway. Grades for NJ* Vol1	2001	x											x		
55 ITE, *Gdln. Urban Major Street Design*	1984		x						x		x				x
56 ITE, *Gdln. Dway. Location & Design*	1987		x						x		x		x	x	x
57 ITE, *Gdln. Res. Subdv. Street Design*	1993		x						x				x		
58 5D-10, "Queuing Areas...", *ITE Journal*	1995	x								x					
59 ITE, draft *Acc. Pub. ROW*	2006		x		x										
60 Kim, "Model. Bicyc. Collisions" TRR 1538	1996	x		x											
61 Kirschbaum, *Des. Sidewalks & Trails*	2001		x												
62 Kockelman, "Swalk Lit. Rev." TRR 1725	2000	x			x										
63 Kockelman, "Meeting ADA" *J. Rehab.*	2001	x			x										
64 Kockelman, "Swalk. X-Slope" TRR 1818	2002	x			x										
65 Koepke, NCHRP 348 *A. M. Activity Centers*	1992	x	x						x	x			x	x	x
66 Lakewood, CO, "Traf. Eng. Des. Policy"	1982		x						x	x	x			x	x
67 Lakewood, CO, "Traf. Eng. Des. Policy"	1985		x										x		
68 Levinson, UConn access mgmt. wkshp.	1984		x						x	x	x		x	x	x
69 McCormick, draft TCRP D-09	2004	x					x		x						
70 McCoy, "Effects of Dway." *ITE J.*	1990	x													
71 McGuirk, *Eval. Factor Dway. Accidents*	1976	x						x					x		
72 Movassaghi, "Geo. Grade Brk." TRR 1445	1994		x										x		
73 Najm, *Analysis Crossing Path Crashes*	2001	x						x							
74 Neuman, NCHRP 279 *Int. Channel. Des.*	1985		x						x		x			x	
75 OR DOT, "Driveway Profile Study"	1998	x											x		
76 Rawlings, "Dway. Collision Patterns"	2008	x				x		x						x	
77 Richards, *Gdln. Dway. Des. & Op.* Vol2	1980	x													
78 S&K, NHI class notebook *Acc. Mgmt.*	2000	x	x												
79 San Buenaventura, CA, "Dway. & Policy"	?		x						x						
80 Smith, "Plan. & Des. Bic. Fac." TRR 570	1976	x		x											
81 Steinfeld, *Stds…Wheeled Mobility*	2005		x		x										
82 Stover, NCHRP 93 *Gdln. Med. & Marginal A*	1970	x	x					x	x		x		x	x	x
83 Stover, *Gdln. Spacing Access,* Bul. 81-1	1981	x	x						x			x	x	x	
84 Stover, intro., 4th Acc. Mgmt. Conf.	2000		x						x			x			x
85 Stover, *Tran. & Land Development* 2ed	2002		x			x			x	x	x			x	x
86 Stutts, *Ped. Crash Types* TRR 1538	1996	x				x									
87 Tarawneh, "Eff. Aux. Ln." *J. Tran. Engr.*	2002	x										x			
88 Tomlinson, "Managing Wch." *Phy. Therapy*	2000	x			x										
89 TRB, Circular 456	1996		x					x							
90 TRB, *Access Management Manual*	2003	x	x			x		x	x		x	x	x	x	x
91 Uckotter, *Analy. Acc. Com. Dway.* 74-9	1974	x						x							
92 Wessels, "Bicycle Collisions" TRR 1538	1996	x		x											
93 Whitman, "Danger Grate" *Proc.Bic/Ped*	1974	x		x											
94 Williams, K., NCHRP Syn. 304	2002		x												x
95 Williams, M., *Recommended Vert. Align.*	1991	x											x		
96 Yurysta, "Effect Com. Veh." TRR 601	1976	x							x						
97 Zeidan, "Effect Rt-Turn Ln." TRR 1737	2000	x						x					x		

literature specifically addressing the design of driveway geometric elements; and

literature addressing other issues, but applicable to the geometric design of driveways.

Examples of literature of the second type include discussions of pedestrian attributes, descriptions of problems caused by drainage appurtenances, or examinations of vehicle turning speeds at intersections.

Literature Categories

The literature identified by the project team members can be broadly characterized as falling into one of two categories, research or guidelines.

1. research: investigation, observation, measurement, or analysis of attributes, behaviors, or data
2. guidelines: recommended practices, which may be based on research findings, experience, or beliefs

Some documents contained both types.

In this review, research studies that emphasized bicyclists, pedestrians, and pedestrians with disabilities were grouped into the non-motorized mode research section. Another section deals with research for which the main focus was motorized modes. Safety research topics were grouped in a third section. A discussion of guidelines is the final technical section of the literature review.

Research on Non-motorized Modes

Until recently, the literature on driveways had been focused on the motorist. Sometimes, the needs of pedestrians or bicyclists were overlooked. However, it is clear that driveway design affects pedestrians and bicyclists. This section of the literature review discusses bicycle and pedestrian attributes as they relate to driveway design and operation.

Bicycles and Drainage Research

The revival of bicycle use in the 1970s brought attention to roadway design choices that had been made without considering the needs of bicyclists. One element that received scrutiny was the grate or grill on openings of storm drain inlets. Examples include grates that are used in combination with curb-opening inlets, and grates that cover an inlet with a top that is flush with the pavement surface, such as a long, narrow flush inlet that extends across the opening of a driveway. These grates were sometimes constructed of bars that were oriented parallel to the movement of traffic. Bicyclists opposed parallel-bar grates, because often the spacing between the bars allowed bicycle tires to drop into the opening between the bars, obviously creating a hazard for bicycle riders.

Many roadway designers favored parallel-bar grates because their hydraulic performance was believed to be better than that of alternative grate designs. Opponents of the parallel-bar grates countered that performance was affected by number of other factors, such as size of the curb inlet opening, size of the opening between bars, and the way that incoming flow was channeled into the grate. Preliminary tests at a hydraulics laboratory identified two grates that were safe for bicycles and performed well hydraulically.

Roadway designers were pressured to find suitable alternatives and change their practices. Cited sources of pressure included:

- actual accidents (a retrofit program in one state, consisting of installing crossbars on existing grates, was instituted after the tire of a moving bicycle slipped into the grate opening, leading to the death of a small child (*Whitman, 1974*);
- threats of legal action; and
- requests from action groups and elected officials.

Pedestrian Characteristics Research

People considering reaching their destination by walking may be affected by comfort and the weather, the length of the trip, the perceived safety of the intended route, the utility of walking as compared with other options, or the availability of an alternative mode. Fitzpatrick reported about ¾ of pedestrian trips cover a distance of 0.5 mile or less (*Fitzpatrick et al., 2006*).

A currently-recommended width to accommodate two side-by-side pedestrians is 4.67 feet (ft) (*AASHTO, July 2004*). A width of at least 5.0 ft is recommended for two wheelchairs to pass by each other side-by-side.

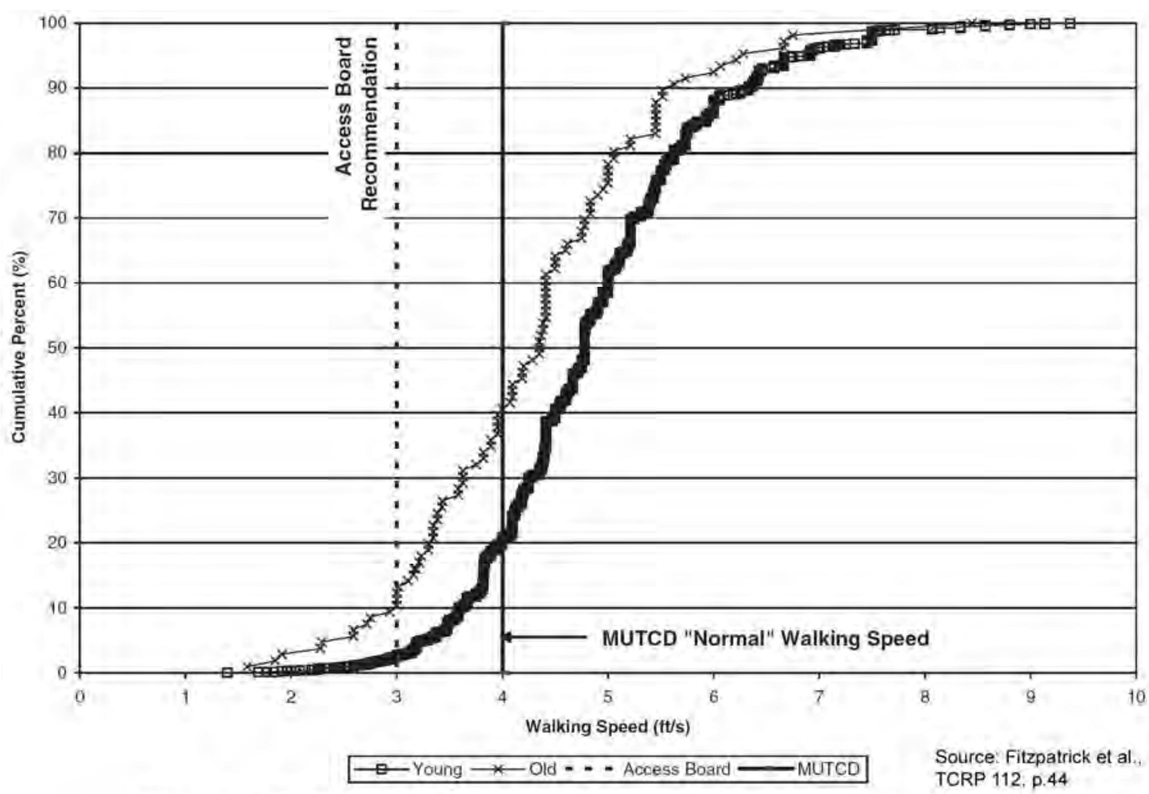
One source listed a range of pedestrian walking speeds from approximately 2.5 to 6.0 fps (*AASHTO, July 2004*). Another stated that various sources report walking speeds ranging from 2.0 to 8.0 ft/s (*Fitzpatrick et al., 2006*). The *Manual of Uniform Traffic Control Devices* (MUTCD)(*FHWA, 2003*) and others have for many years used a 4.0 ft/sec walking speed for pedestrian-related design. This value has come under increasing criticism for being too high, especially for young, elderly, or disabled pedestrians. A recent study recommended a walking speed of 3.5 ft/s (1.1 m/s) for the general population, and 3.0 ft/s (0.9 m/s) where older pedestrians were a concern (*Fitzpatrick et al., 2006*).

Exhibit 2-2 lists walking speeds by age group and gender. Speeds of pedestrians over age 60 were less than the speeds of those between 13 and 60. In all of the groups, the average speed is well over 4 ft/s, but more than 15% walk at a speed of less than 4 ft/s. This exhibit is followed by Exhibit 2-3, showing a cumulative distribution plot of walking speeds.

EXHIBIT 2-2 Walking speed by age and gender

Age Group	Sample Size	Walking Speed, ft/s (m/s) 15th Percentile	50th Percentile
		Male	
13-60	1434	3.75 (1.14)	4.78 (1.46)
Over 60	75	3.11 (0.95)	4.19 (1.28)
ALL	1509	3.67 (1.12)	4.75 (1.45)
		Female	
13-60	890	3.79 (1.16)	4.67 (1.42)
Over 60	31	2.82 (0.86)	4.41 (1.34)
ALL	921	3.75 (1.14)	4.67 (1.42)
		Both Genders	
13-60	2324	3.77 (1.15)	4.74 (1.45)
Over 60	106	3.03 (0.92)	4.25 (1.30)
ALL	2430	3.70 (1.13)	4.72 (1.44)

Source: Fitzpatrick et al., TCRP 112, p.44



Older than 60 (Old) and 60 and younger than 60 (Young) walking speed distribution.

EXHIBIT 2-3 Cumulative distribution of walking speeds

A 1980s study in Great Britain reported that 14% of individuals over 15 years of age had physical, sensory, or mental handicaps (*Fitzpatrick et al., 2006*). The list (see Exhibit 2-4) shows that the walking speeds of some disabled persons are below average.

A recently published AASHTO guide for pedestrian facilities included the following categories of pedestrians (see Exhibit 2-5) whose attributes may not be fully accommodated by design values that are suitable for the general adult population (*AASHTO, July 2004*).

EXHIBIT 2-4 Average walking speeds for disabled pedestrians

Disability or Assistive Device	Mean Walking Speed ft/s (m/s)
Cane or Crutch	2.62 (0.80)
Walker	2.07 (0.63)
Wheel Chair	3.55 (1.08)
Immobilized Knee	3.50 (1.07)
Below Knee Amputee	2.46 (0.75)
Above Knee Amputee	1.97 (0.60)
Hip Arthritis	2.24 to 3.66 (0.68 to 1.16)
Rheumatoid Arthritis (Knee)	2.46 (0.75)

Sources: Fitzpatrick et al., TCRP 112, p. 8, and Dewar, " Pedestrians and Bicyclists," *Human Factors in Traffic Safety*, Chp. 18, p. 571, Lawyers and Judges Publishing Company, Tucson, AZ, 2002

EXHIBIT 2-5 Special considerations for pedestrian subgroups

Pedestrian subgroup	Considerations
Ambulatory impairments (mobility aids include wheelchairs, crutches, canes, walkers, prosthetic limbs)	may have lower speed; adversely affected by steep grades, steep cross slopes (p12)
Hearing impairments	must rely more on adequate vision (p13)
Vision impairments	rely on surface contrast, texture, sound, consistency/predictability of layout
Children	due to smaller size: do not have the same field-of-view as adults; may not be as easily seen by motorists (p32)

Source: Am. Assn. of State Hwy. and Transportation Officials, *Guide for the Planning, Design, and Operation of Pedestrian Facilities*, Washington, DC, 2004. Used by permission.

Among the number of papers that have considered wheelchair design and seating are those by Brubaker (*1986*) and by Tomlinson (*2000*). Research at the University of Buffalo (Steinfeld et al., 2005) found that U.S. wheeled mobility device user eye-heights ranged from 1090 to 1295 mm, and concluded that current standards were too high (see Exhibit 2-6). They speculated that earlier research may have omitted shorter people.

A study that considered a variety of pedestrian street crossing behaviors made note of which pedestrians were transit riders, when a transit stop was within the view of the cameras. It was observed that a "small but notably larger percentage of transit pedestrians ran or walk/ran [while crossing the roadway] as compared to the general population" (*Fitzpatrick et al., 2006*).

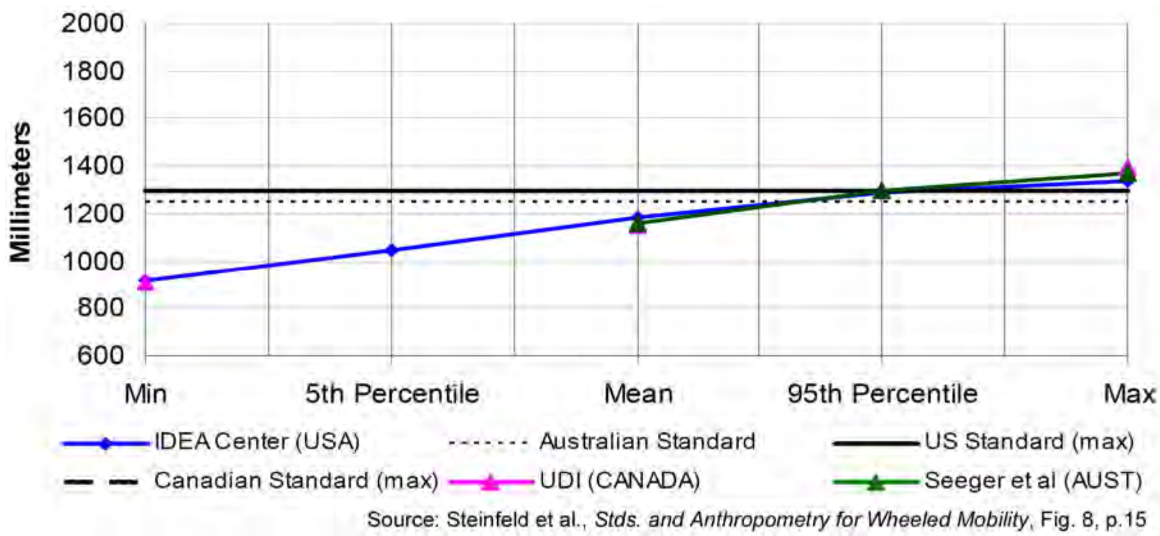


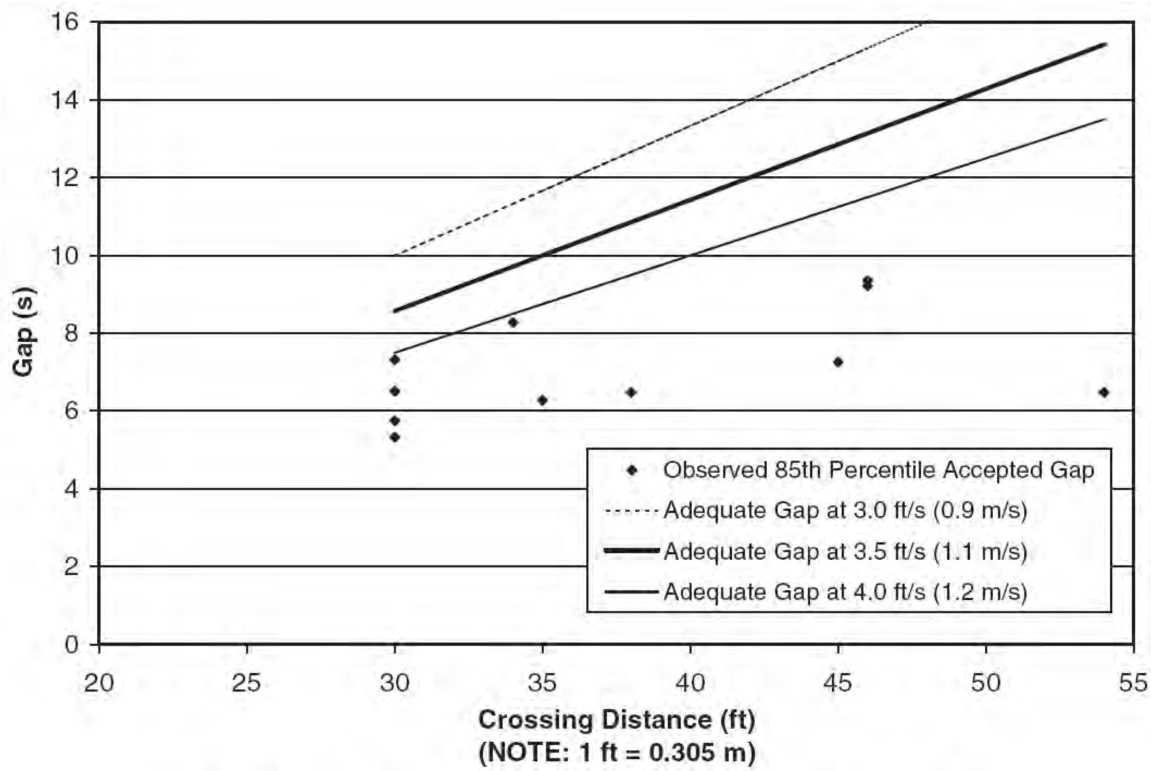
EXHIBIT 2-6 Wheeled mobility eye height

Pedestrian Gap Acceptance Research

Gap acceptance, in this context, refers to the size of the interval between successive vehicles that pedestrians consider adequate for a safe crossing. Among the possible applications include pedestrians on the sidewalk as they approach the driveway, concerned that vehicles will not yield the right-of-way to them, attempting to project the time that oncoming vehicles would arrive at the driveway entry.

During field studies, especially at high-volume traffic sites, pedestrians did not require that all lanes be completely clear. Instead, pedestrians projected the trajectory of vehicles and utilized a "rolling gap" to cross the street, so that there was a gap in each lane of traffic that coincided with the pedestrian's trajectory as they crossed the street. Exhibit 2-7 is a plot of logit model analysis that identifies the 85th-percentile accepted gaps (*Fitzpatrick et al., 2006*).

Blind pedestrians participating in a study of their gap acceptance were about 2-½ times less likely to make correct judgments about gaps than sighted participants. Blind pedestrians took significantly longer to detect crossable gaps, and were more likely to miss crossable gaps altogether (*Guth et al., 2005*).



Comparison of trends for observed 85th percentile accepted gaps and calculated critical gaps for walking speeds of 3.0, 3.5, and 4.0 ft/s (0.9, 1.05, and 1.2 m/s). Source: Fitzpatrick et al., TCRP 112, p.55

EXHIBIT 2-7 Pedestrian gap acceptance

Research on the Effects of Cross Slope on Disabled Pedestrians

A feature of particular concern to pedestrians with ambulatory disabilities is the cross slope of the walking surface. *Accessible Rights of Way: A Design Guide* (*Access Board, 1999*) states: “Excessive cross slope is a major barrier to travel along sidewalks for pedestrians who use wheelchairs and scooters, pedestrians who use walkers and crutches, pedestrians who have braces or lower-limb prostheses, and those with gait, balance, and stamina impairments. Energy that might otherwise be used in forward travel must be expended to resist the perpendicular force of a cross slope along a travel route. Cross slopes that exceed 1:48 (2%) significantly impede forward progress on an uphill slope and compromise control and balance in downhill travel and on turns." The Access Board's training video (*Access Board DVD, 1999*) on sidewalk accessibility states that for wheelchair users, 50% more effort is required to traverse a 3% cross slope than to traverse a 2% cross slope.

That statement has been questioned by Kockelman and others in research funded by the Texas Department of Transportation (*Kockelman et al., 2001; Kockelman et al. 2002*). The research objective was to determine if the 2% maximum cross slope specified in the ADA Standards is appropriate in certain existing right-of-way alteration situations where conditions do not allow for the specified maximum without considerable extra expense. Note that Kockelman's perspective not accepted by many of those who determine accessibility standards and codes. Quoting from the Kockelman et al. literature review (*Kockelman et al., 2000*):

> "…In fact, very few articles deal directly with the effects of cross slope: most focus on the directional stability of wheelchairs. With the exception of recent research performed by Kockelman et al., no studies could be found pertaining to the effects of cross slope on people who use other walking aids, such as crutches and walkers, and no studies included experiments conducted in actual sidewalk environments.
>
> In a film … Cannon states that 50 percent more effort is required for a wheelchair user to traverse a 3 percent cross slope relative to a 2 percent cross slope. Cannon goes on to point out that, for wheelchair users, there is increased difficulty in traversing a cross slope in combination with a primary grade, such as that on a ramp. He also points out that, the greater the cross slope, the more likely slipping is to occur, especially under wet or icy conditions. Finally, he illustrates some of the differences in motorized and manual wheelchairs, though not specifically in the context of cross slope.
>
> On the basis of a review of scientific literature on cross-slope design, the conclusion must be drawn that prior research is insufficient to support the ADA 2 percent cross-slope requirement. … However, Chesney and Axelson's work suggests that the difference in wheelchair-user effort between traversing cross slopes in the range of 2 percent to 5 percent may not be very large (about 20 percent), …."

The findings of that research suggested that in general, people with disabilities were able to negotiate cross slopes of up to 6% on relatively level paths. However, both the US Department of Justice, in court documents, and the US Access Board, in an unpublished internal memo (both available under Freedom of Information Act requests), have been very critical of these findings and the studies upon which they are based. An unpublished 2004 Access Board memo written by Scott discussed serious problems in the sample size and statistical analysis that should preclude these studies from serious consideration.

Reported problems with driveways for pedestrians who are blind or who have low vision are related to wayfinding and to veering down the slope of the driveway into the street (*Hill and Ponder, 1976; Guth and Rieser, 1997*). It has been suggested that minimizing the cross slope of the sidewalk, in combination with a driveway that has a distinct slope between the sidewalk and the roadway, would provide a cue that would be usable by blind or low vision pedestrians. Related research has evaluated the ability of blind pedestrians to travel in a straight line without 'veering' when crossing streets or open spaces, such as plazas or parking lots, rather than driveways (*Guth and LaDuke, 1995; Guth and Rieser, 1997*).

Research on Motorized Modes

As would be expected, a considerable amount of research has examined the effects of driveway characteristics on motor vehicle operation. While the topics of access management and motorist yielding behavior (to pedestrians) are discussed briefly, the bulk of this section addresses the effects of driveway horizontal and vertical alignment on motor vehicle operation.

Research on Access Management

There is a sizable body of literature reporting the benefits of access management. Effort is better directed toward other topics rather than duplicating this readily available literature. Therefore, references are made to only a few access management publications.

A National Highway Institute (NHI) class manual and an NCHRP report are among the more-widely disseminated access management publications. The NHI course manual (NHI Course 133078) reported a range of crash reduction benefits, from 20% when right turn bays are added, to 67% when left turn dividers are installed (*S&K, 2000*). The work by Gluck et al. (*1997*) investigated and reported a myriad of impacts related to access management. The report documented the impacts on both safety and traffic flow arising from driveway vehicles either leaving or entering the roadway. Analysis of more than 35,000 accidents found that crash rates rise with increasing access density and signalized access density. Roadways with medians had the lowest rates at all access densities.

Studies in the 1970s of data from Indiana roadways found that for two intersecting streams of traffic, the volume product (i.e., product of the two volumes) was a better predictor of crashes than the sum of the two volumes (*Uckotter, 1974*). Each of the analyses performed on two sets of data, one obtained from *NCHRP Report 420* and the other from Minnesota, showed that the crash rate doubled when the number of access points per mile increased from 10 to 40 (*Gluck and Levinson, 2000*).

In 2003, the Transportation Research Board released the first edition of the *Access Management Manual*, a comprehensive publication that discussed a broad range of topics related to access management. It stated that for up to about 40 access points per mile, crash rates seem to vary with the square root of access density (*Committee, 2003*).

Research on Auxiliary Lanes

A set of curves from a Kansas State University study (*Hasan T. and Stokes, 1996*) is one example of the types of procedures or warrants for when right-turn deceleration lanes should be provided. Tarawneh and Tarawneh (*2002*) found that auxiliary lane length and right-turn volumes downstream of the driveway contributed to the use of the auxiliary lanes. In lieu of observing evasive maneuvers in the outside lane as a means to determine the need for a right-turn lane, Hadi and Thakkar (*2003*) studied speed differentials. They developed a table showing the benefit-cost ratio for providing a right turn lane for pairs of volumes and speeds.

McCoy and Heimann (*1990*) investigated the effects on the saturation flow rate of the arterial roadway due to right-turn traffic entering or leaving driveways near signalized intersections. They observed 148 headway pairs (i.e. the headway between a vehicle and the immediately following vehicle) in queues of through passenger cars passing through the nearby signalized intersection at two sites. They found that driveway traffic can reduce the saturation flow rates on signalized intersection approaches. The amount of reduction depends on the corner clearance of the driveway and the proportion of right-lane traffic that enters and exits the driveway. Traffic entering driveways was found to increase headways (and therefore adversely affect the saturation flow rate) by about 1 to 2 seconds, with the greatest effect for driveways close to the intersection. The effects due to vehicles from the driveway turning into the arterial were influenced by the difference in downstream turning radii. For a driveway that was 105 feet from the intersection, where the proportion of curb-lane volume entering the driveway and the proportion of curb-lane volume exiting the driveway are both 20%, the estimated reduction in the right-lane saturation flow rate was 23%.

An important safety consideration is the impacts of right turns into driveways on the sight distance of vehicles exiting from the driveway. Zeiden and McCoy (*2000*) found that vehicles in a right-turn lane could restrict the lines-of-sight of motorists exiting driveways. They suggested designing the right-turn lane with a wider cross section, 19 to 30 ft, which allows space for a longitudinal separation between the through lanes and the right-turn lane.

Research on Driveway Entry and Turning Vehicle Dimensions

The elements of driveway entry width (throat width), entry shape (e.g., curved radius or straight taper), and entry shape dimensions (size of radius or taper length) cannot be considered separately, because the driver of a turning vehicle is responding to the combination of all three. Issues of interest for vehicles turning into or out of driveways, as affected by the width, shape, and shape dimensions include the:

- lateral position of the vehicle (on the roadway, during the turn, or in the driveway) with respect to lane or pavement edges;
- speed of the vehicle, especially when intersecting the paths of other users;
- speed at which the turn is made; and
- change of speed with respect to the positions of other motorized or nonmotorized users.

The deceleration or acceleration of the driveway vehicle creates a speed differential with through traffic, which may increase the chances of rear-end or other types of collisions. For a vehicle intent on turning into the driveway, the farther away from the driveway that the turning vehicle decelerates, the greater the perception-reaction time available for a bicyclist or pedestrian crossing the driveway entry.

The fourth edition of McGraw-Hill's *Time-Saver Standards* (*Callender, 1966*), an architectural handbook, included material for identifying the minimum design radius for driveway curves. The text stated:

> "Data … were adapted from material … which appeared in the September, 1933 issue of *American Architect* …." An accompanying note editorialized "In spite of the antiquity of these pages, they are less obsolete than one might imagine. The three dimensions … on which these designs are based have changed surprisingly little for the largest cars … Tread has not changed at all and wheelbase only slightly. The turning radius, however, of even the largest 1964 cars is considerably less..."

It was also pointed out that recommended widths had increased by about a foot since 1933, and were [in 1966] 9 ft. for straight driveways. A number of figures showed the principles applied to designing curving or circular driveways leading up to the front door of a structure. Exhibit 2-8 is shown as one example figure.

Stover et al. (*1970*) analyzed time-lapse photography of actual traffic streams and concluded that for typical major urban roadway volumes and speeds (45 miles per hour, mph), a driveway entry speed (the vector measured along the main roadway as the rear of the vehicle clears the through lane) of 10 to 15 mph was desirable to minimize interference with through traffic. They also referred to Solomon's study, showing rural highway speed differentials of greater than 10 mph were correlated with increased accident potential. Comparing the paths of vehicles turning at a radius of 5 ft with a driveway width of 35 ft to vehicles turning at a 10 ft radius and 30 ft width, Stover stated that the "dispersion of vehicles trajectories decreases when the curb return radius is increased,", … but it is still substantial with a radius of 10 ft.

Stover and Richards (*Stover et al, 1970; Stover, 1981; Richards, 1980*) examined the effects of driveway width and radius on entry speeds. Stover stated:

> "Recent research [then 1979] shows that with commonly used curb return radii and throat widths, the right turning vehicle enters a driveway at about 10 mph. … While the average speed profile with respect to time is different for different combinations of curb return radii and throat width, the range is rather limited. Further, the speed of the

vehicle when it clears the through traffic lane is not appreciably different." (*Stover, 1981*.

He went on to note that an increase in the curb return radius was associated with a decrease in the dispersion of the paths of turning vehicles. When the curb return radius exceeded 10 ft, driveway throat width had little influence on the paths of turning vehicles (*Stover, 1981*).

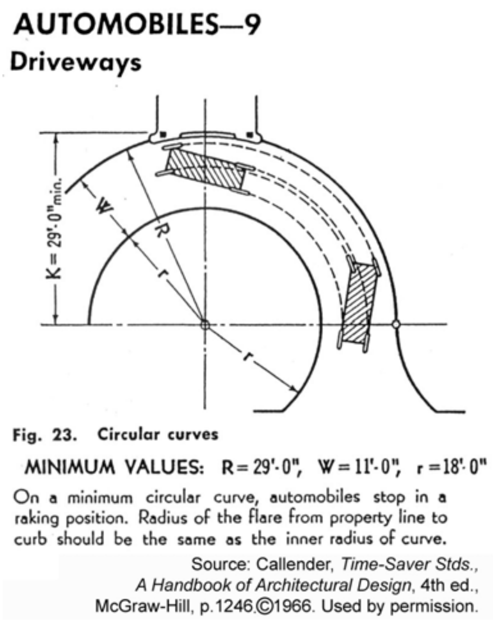


EXHIBIT 2-8 Circular driveway design

Richards reported findings from studies of driveways at a test track. Using an instrumented vehicle that was 17.7 ft long and 6.3 ft wide, 54 drivers made a total of 1400 driveway entry and exit maneuvers. Speed was measured with a fifth wheel attached to the rear bumper, behind the left (i.e., outside) wheel. Lateral positions were noted by two roadside observers who recorded the position of the right front tires as vehicles passed over each of six sets of reference markers on the pavement surface. Tests were conducted with various driveway configurations. For Study 1, there were 10 different driveway designs. The widths ranged 20 to 35 ft, and radii ranged from 0 to 30 ft. No vehicle was trying to exit the driveway. The average speeds of vehicles approaching the different configurations did not vary until within about 100 ft before turning into the driveways. At the entry, average speeds ranged from 9 to 13.5 mph (*Richards, 1980*).

During Study 2, Richards compared paths of vehicles turning right into 35 ft wide driveways when vehicles exiting the driveway were present. Three different lateral positions of exiting vehicles were used. The study then compared the positions of a vehicle turning right into a driveway with a 5 ft radius with those of a vehicle turning at a 20 ft radius. At the driveway with the 20 ft radius, vehicles turning right into a driveway "tended to parallel the entry curb line" and drivers were less likely to encroach into the driveway exit (p 61). At the driveway with the 5 ft entry radius, drivers "tended to make a wide turn using all of the available throat width". Among the different configurations of radius and lateral position of exiting vehicle, the range of average speeds of the entering vehicles was for the most part less than 3 mph. The one exception was for the configuration with a 5 ft radius and only 10 ft of entry width available: the average speed was anywhere from 1 to 5 mph below the other over the deceleration distance, and the speed pattern was erratic (*Richards, 1980*).

Stover and Richards' exhibits have been widely reproduced. Exhibits 2-9 and 2-10 show vehicle patterns upstream of and at the driveway entry. Contrasting the speeds of vehicles approaching a 25 ft wide driveway having here a 5 ft or a 20 ft entry radius, a maximum speed difference of almost 5 mph was observed about three seconds in advance of the driveway. At one second in advance of the entry, there was about a 3 mph difference between the two radii. At a driveway with sufficient width for two lanes of traffic, changing either the width or the curb radius had a small effect on speed; the effect was slightly larger when both changed.

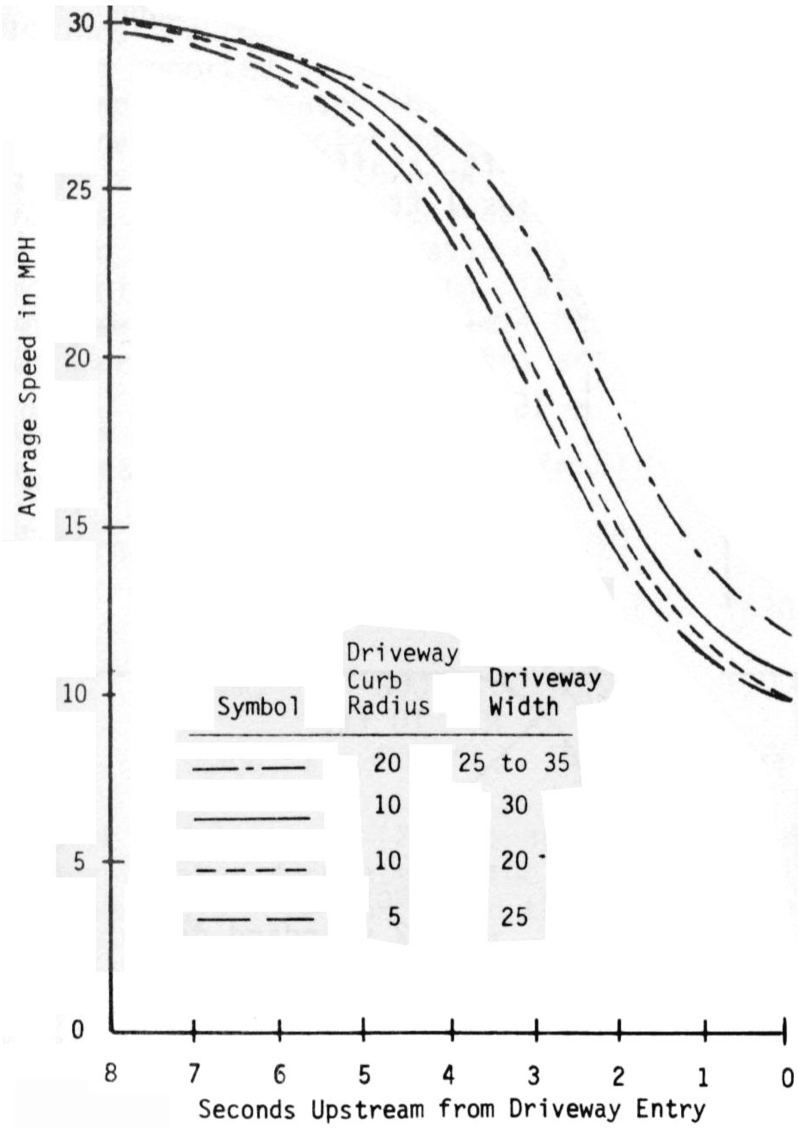
Their analyses included the distribution of the vehicle entry paths along the curb lane and driveway for a 13-ft wide curb lane (12 ft lane plus 1 ft gutter), 10 ft radius, and 30 ft wide driveway. The plot of the inside front wheel path of right-turning vehicles at a 30 ft wide driveway with a 10 ft radius shows a good deal of encroachment into the space intended for vehicles exiting the driveway. Not included is a similar plot for a driveway with a 5 ft radius and 35 ft throat width.

Azzeh et al. performed an extensive synthesis of access related literature that focused on the impact of controlling access to commercial properties on arterial highways to promote safety and efficiency. Their report also addressed driveway dimensions, stating:

> "Several driveway dimensions in combination affect the maximum turning radius of a vehicle, which in turn affect the maximum turning speed. These are driveway lane width, length, angle, return radius, and offset. For low volume driveways, the total driveway width can be used for turning. For higher volume driveways where head-on conflicts are frequent, lane width should consider only a one-direction lane."

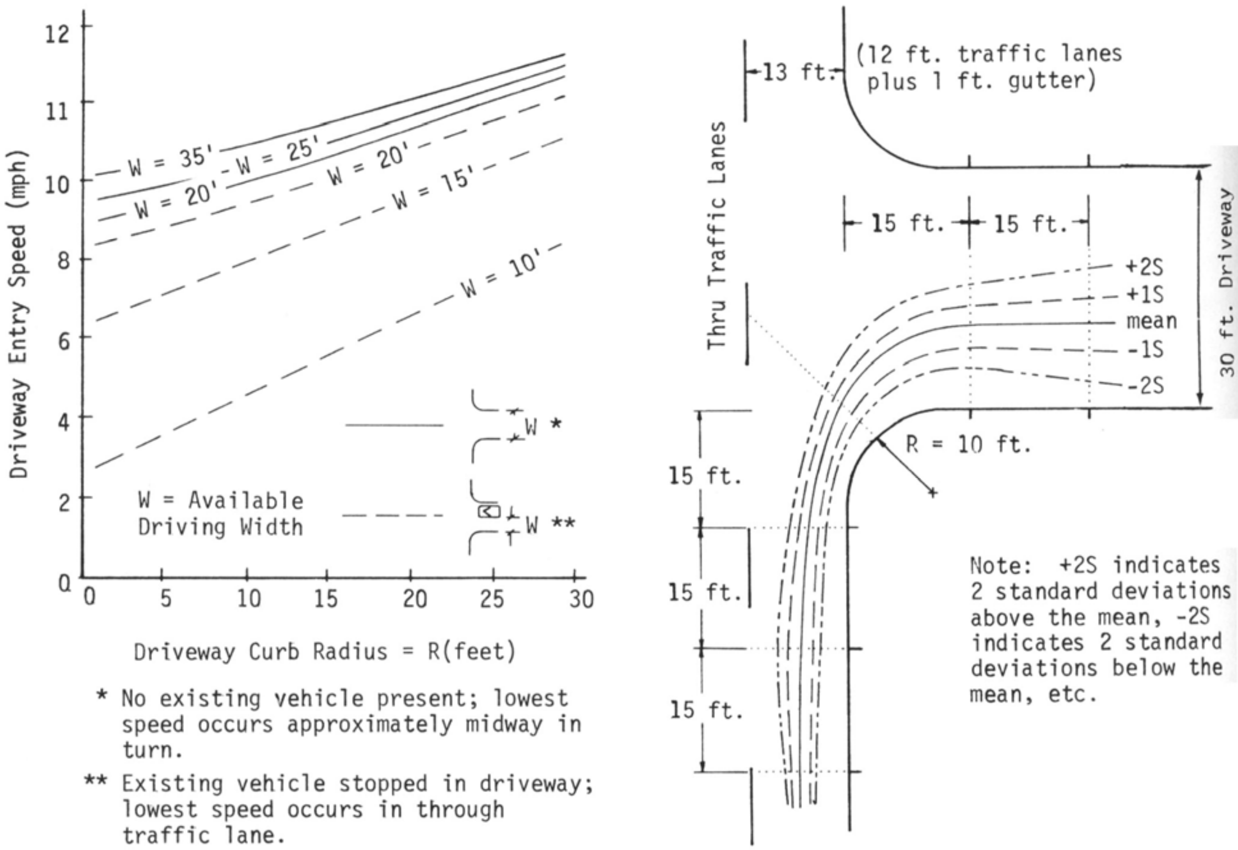
The report included recommended dimensions and a driveway entry design formula (*Azzeh, 1975*) in which needed width decreased as the driveway edge radius increased.

$$W = 8.6 + R - r - \{R - r - \Delta - 2 - [\sqrt{\Delta (2R - 2r - \Delta - 4)} / \tan \Theta]\} \cos \Theta - \sqrt{\Delta (2R - 2r - \Delta - 4)} / \sin \Theta$$



Source: *Synthesis of Saf. Res.*, p.4-7

EXHIBIT 2-9 Upstream speed of vehicle turning into driveway



5. Speed of Auto Entering Driveway as a Function of Curb Radius and Available Driveway Width

6. Path of Right Front Wheel for Selected Driveway Design

Source: *Synthesis of Saf. Res.*, p.4-8

EXHIBIT 2-10 Speed and path attributes of vehicles entering the driveway

where W = driveway lane width, ft

R = radius of vehicle path, ft

r = radius of driveway edge (curb return), ft

Δ = driveway offset, ft

Θ = driveway angle, degrees

The procedure incorporated the following assumptions.

vehicle width = 6.6 ft;

clearance from right edge of the vehicle to driveway edge = approximately 2 ft;

a geometrically approximated vehicle turning path;

AASHTO side friction factors (i.e., for 6.6 mph, R = 30 ft; for 10 mph, R = 40 ft; for 15 mph, R = 50 ft)

For a 10 mph turning speed and no offset, Azzeh et al. recommended the following combinations of radius and driveway lane width.

Radius = 15 ft, width = 23 ft   Radius = 20 ft, width = 20 ft   Radius = 25 ft, width = 16 ft

Azzeh et al. also determined a minimum driveway length to be the sum of the length required to complete a circular turn plus the length to decelerate at a rate of 8.5 ft/s^2 from the turning speed to a stop.

Flora and Keitt (*1982*) based their list of the factors that affect the speed at which vehicles can safely turn into driveway on the work of Azzeh et al., but expressed them in a slightly different way. As Exhibit 2-11 shows, Flora and Keitt listed the factors as driveway width, return radius, lateral offset, approach angle, approach flare, and usable driveway length.

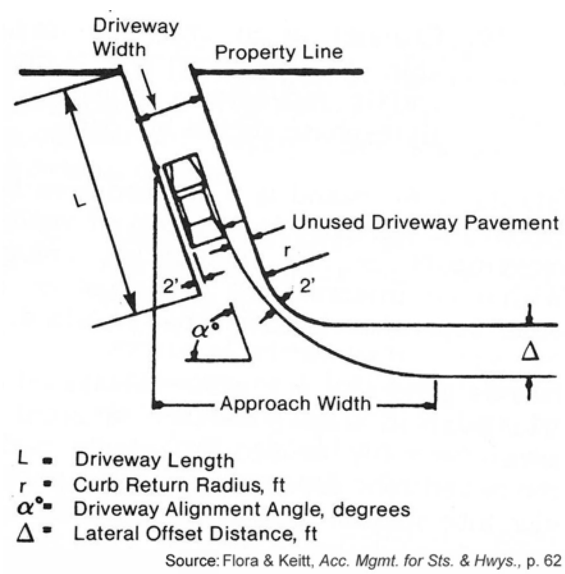


EXHIBIT 2-11 Flora and Keitt driveway design elements

To measure the speeds of right turning vehicles at an intersection, Yurysta and Michael (*1976*) recorded the elapsed time required for the maneuver at 19 corners. They recorded only vehicles traveling in free-flow for the entire distance. The measurements began and terminated at a point 60 ft from the PI (point of intersection of the curve tangents). Each corner radius was measured as a simple curve. The radius was transformed and stepwise linear regression was used to correlate radius and vehicle speed. Separate analyses were performed for passenger car speeds and for truck speeds. Exhibit 2-12 presents two figures from their report, showing vehicle turning speed as a function of curb radius. For passenger cars, doubling the curb radius from 10 ft to 20 ft was associated with a speed increase of less than 2 mph.

Stover and Koepke (*2000*) showed how increasing the driveway "offset" from the curb allows a shorter driveway radius. Box (*Sep. 1969*) gave simplified examples showing a tight turning radius requiring the swept path of a vehicle to encroach on the opposing lanes of a 30-ft driveway, and a larger radius that enables right turning vehicles to stay within the proper entry lane.

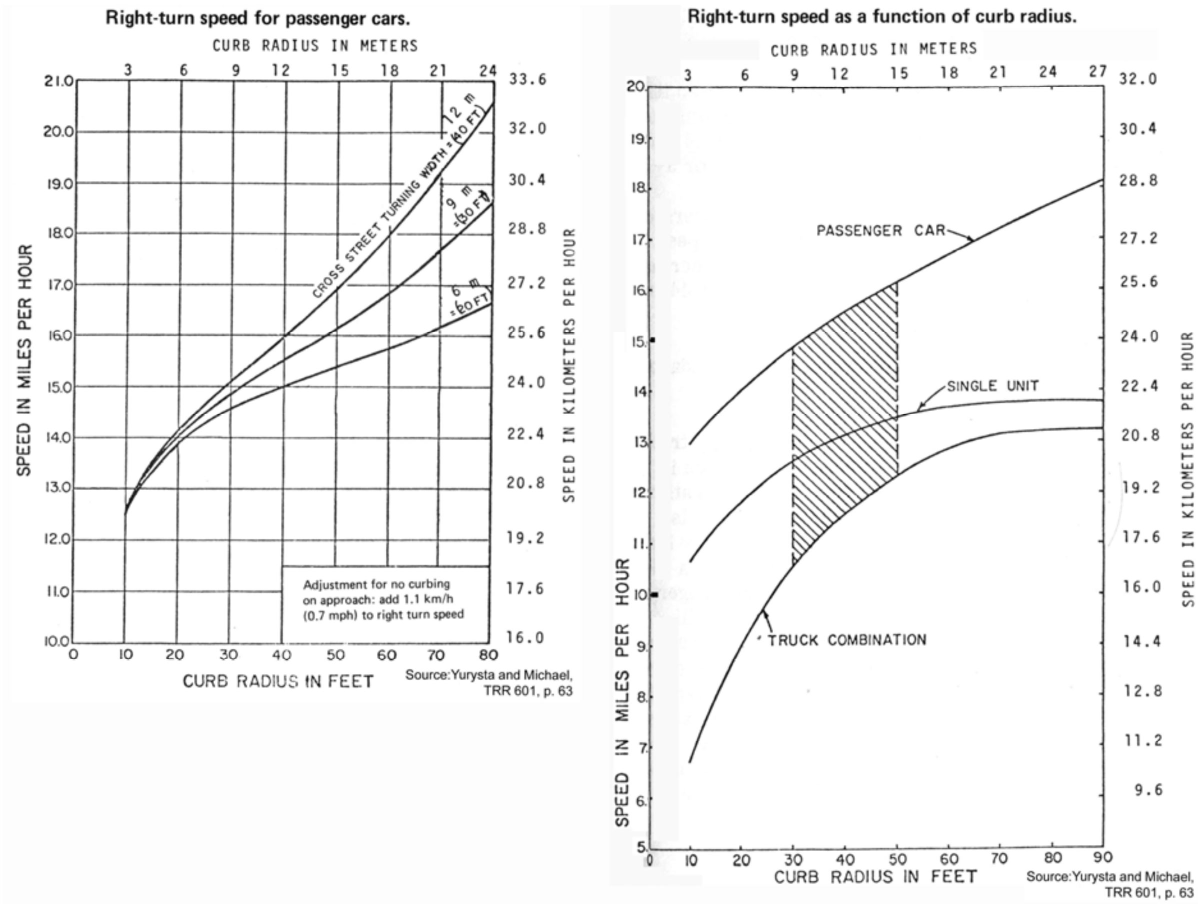


EXHIBIT 2-12 Effect of turning radius on speed

Considering the paths of long trucks turning corners in urban areas, DeCabooter and Solberg (*1989*) deployed a camera on a crane 200 ft in the air along with ground cameras to record the turning paths of large trucks at four urban intersections. They observed that drivers of large trucks wanting to turn right at confined locations use the width of the oncoming lane in the roadway they are turning into, but to do this, the traffic stream from the right has to have adequate sized gaps in oncoming traffic. Their drawings show that actual right-turning vehicles exhibit a range of lateral tracking paths at any given intersection. They concluded that for the expected mix of trucks to turn right, the curb-to-curb width cannot be less than 40 ft. Note that their drawings show trucks positioned to the right of the roadway centerline when the right turn begins, but making use of most of the width of the roadway that the truck is turning into. Exhibit 2-13 is a nomograph from this research.

In NCHRP Report 348, Koepke and Levinson (*1992*) addressed a number of driveway design issues, including throat length, sight distance, turning radii, and profile/grade. They presented the “entry width” as a separate entity from overall driveway width, and defined it as the width needed at the driveway throat to “accommodate the swept path of the turning design vehicle.”

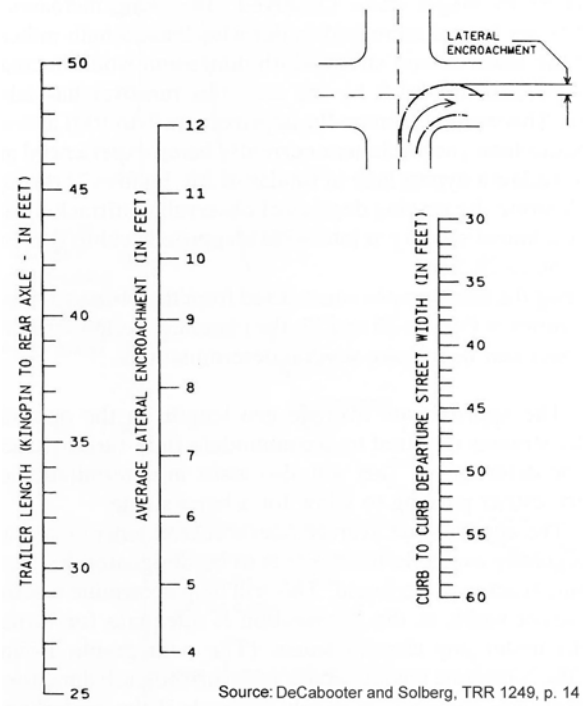


EXHIBIT 2-13 Nomograph for lateral encroachment

Assumed turning paths for design vehicles may not correlate well with actual observed vehicle turning paths. Among the observations from a study in the late 1990s was that the AASHTO bus design template did not reflect the protruding overhang at the outside-rear turning of C- and D-size school buses at the beginning of a turn (*Gattis and Howard, 1999*). In a more recent study of the turning paths of bus transit vehicles, pavement markings were installed at 1 ft intervals on three radial lines. The three radial lines were located near the beginning, midpoint, and end of the turn. Observers were said to be discreetly positioned to avoid alerting drivers. The observed vehicle paths differed considerably from the plot generated by a popular computer software programs (*McCormick, 2004*). The report also noted that "AASHTO design vehicles generally represented the high end of the turning radii among the vehicles surveyed". The researchers postulated that in low-speed and unconstrained situations, characteristics of the individual driver may have as much of an affect on the turning path as vehicle turning characteristics.

The vehicle queueing that is found at commercial establishments such as restaurants and banks with drive-through facilities can block a driveway if the site does not contain adequate space to accommodate the queueing. Stover and Koepke (*2002*) provide some information about the needed "on-site reservoir space to permit the stacking of vehicles waiting to be served at a drive-through window". An ITE informational report lists the observed maximum queue lengths for a few facility types. Maximum queue lengths at fast-food restaurants seldom exceeded nine vehicles (*ITE, 1995*).

Research on Driveway Pavement Markings and Channelization

Richards observed lane encroachments at three shopping driveways and at three government building driveways. The following table (Exhibit 2-14) derived from the reported data shows the percentages of those drivers exiting the driveways that positioned their vehicles so as to leave less than 12 ft for drivers entering the driveway. The listing for driveway 6 shows observations at the same driveway without and with a marked centerline (CL).

EXHIBIT 2-14 Effects of centerlines on lateral position

Type	Width (ft)	Radius (ft)	Centerline marking	% of Lt turn exit leaving less than 12 ft for entry side	% of Rt turn exit leaving less than 12 ft for entry side
1 government building	24	15	none	23	23
2 government building	23	15	none	30	40
3 shopping mall	32	20	none	11	0
4 shopping mall	52	20	none	0	0
5 shopping mall	30	15	solid yellow	no exiting traffic crossed the CL	
6 government building	25	15	none	13	7
6 government building	25	15	solid yellow	2	2

Source: Richards, TTI 5183-2

Even for the three driveways that clearly fall into the two-lane width category (1, 2, 6), the presence of a marked centerline would seem to offer some benefits, in that drivers respond by positioning their vehicles so that they are less likely to block the space for entering vehicles. The report stated "These studies should be considered exploratory in nature…" (*Richards, 1980*).

Richards also showed subjects graphics of driveways with either yellow, white, or no centerline pavement markings. Almost all of the subjects thought that it was alright to enter or exit the driveways with solid either yellow centerline markings or no pavement markings. However, for driveways with either solid or broken white centerlines, over 1/3 interpreted the markings as prohibiting two-way operation, i.e., being a one-way driveway (*Richards, 1980*).

Richards observed driver behavior at a driveway channelizing island with a 6 in high curb. This driveway island design was intended to allow only right turn entry or exit maneuvers. Island dimensions were not given. No signs were present to indicate prohibited or allowed movements. Of the 167 maneuvers observed, 46% were improper left turn entry maneuvers. One of these resulted in the vehicle entering and continuing down the exit side of the channelized driveway (*Richards, 1980*).

Aksan and Layton (*1998*) also noted how drivers respond to triangular islands placed at the connections of a driveway with a roadway. They concluded that the location of the driveway having the triangular island with respect to other driveways serving the same site affects the likelihood of a violation, and that drivers are more likely to violate the intent of these islands if so doing will decrease the travel time. At the 20 intersections viewed, there were more left-turn in violations than left-turn out. Wrong way movements were seen at four locations, one of them involving a vehicle traveling 150 ft down the wrong side of the driveway.

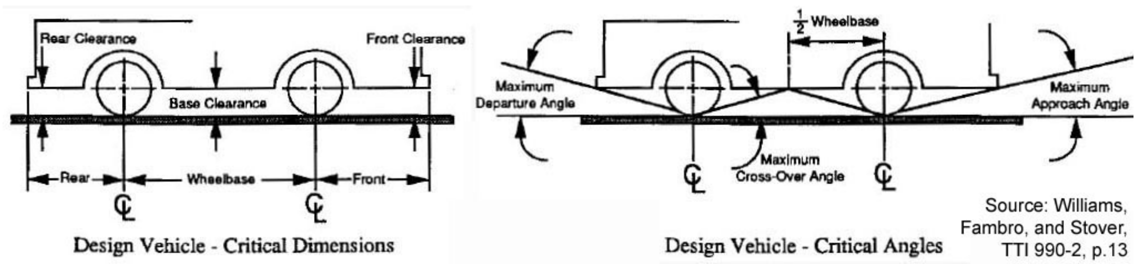
Research on Vertical Alignment

Certain combinations of motor vehicle dimensions and geometric design element dimensions can produce situations where it is physically difficult or impossible for some vehicles to traverse the driveway entry.

To address the design of driveways that needed to be realigned during roadway reconstruction and widening projects, Williams, Fambro, and Stover (*1991*) developed design guidelines for driveway vertical alignment. They noted that the absence of specific guidelines led to a variety of problems associated with inadequate driveway vertical alignment, and one manifestation of inadequate vertical alignment was that the underside of vehicles attempting to negotiate the driveway would contact the pavement surface. Safety concerns arose from the speed differentials between vehicles entering and exiting the driveway and vehicles in the primary traffic lanes, and from inadequate sight distance for vehicles exiting from the driveway. Operational problems were linked to driver discomfort arising from poor vertical alignment such as bumps, steep grades, and abrupt changes in grade.

These problems were believed to be especially pronounced when either of two conditions was present. The first was hilly terrain where right-of-way availability was constrained. The second involved locations where the driveway design had to accommodate vehicles having restrictive characteristics. In these instances, a variety of wheelbases, underside clearances, operational performance, and other characteristics must be taken into account in the design of the driveway alignment.

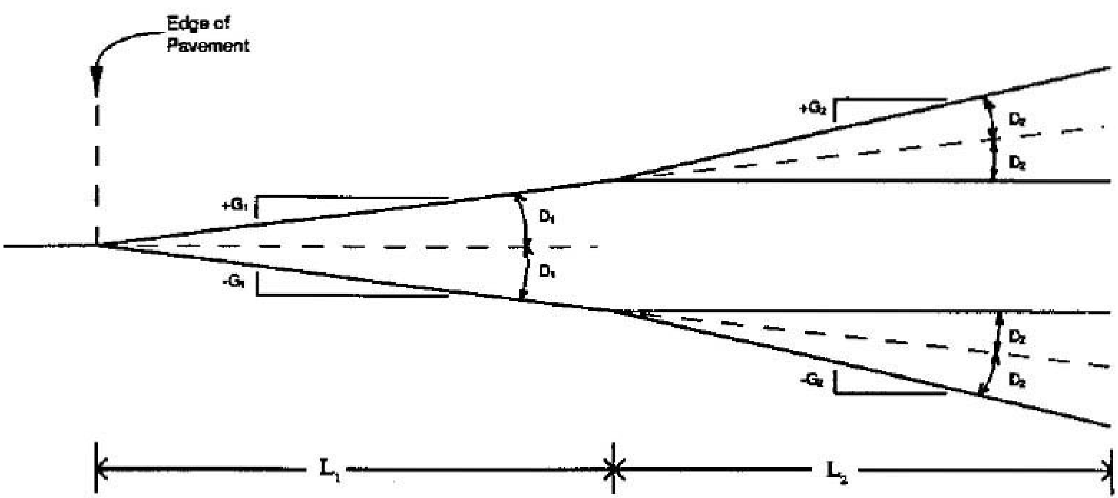
An assessment of the types of vehicles that are expected to use a particular driveway should yield the physical dimensions and operational characteristics that are necessary to establish a design vehicle for the driveway. The physical dimensions of the design vehicles will be needed to determine the guidelines for grade changes. Critical dimensions of design vehicles include lengths and clearances for the front, rear, and wheelbase. Critical angles can be determined from these dimensions and include approach and departure angles, used to determine the critical sag grade breaks and crossover angles, used to determine the critical crest grade breaks. Exhibit 2-15 shows these dimensions.



Source: Williams, Fambro, and Stover, TTI 990-2, p.13

EXHIBIT 2-15 Critical vehicle dimensions and angles

The authors proposed that driveways should conform to specifications that are derived based on the driveway location's area type, along with the functional classification of the driveway and adjacent roadway. Additional considerations include the presence of curbs and gutters, shoulders, sidewalks, superelevated sections, and drainage factors. They presented four basic profiles, two urban and two rural. A design chart (see Exhibit 2-16) suggested maximum grades, maximum changes in grade, and minimum lengths of initial grades. The authors recognized that combinations of multiple design elements could alter the alignment beyond the four basic examples. In those cases, it is up to the design engineer to evaluate and refine each design once the basic guidelines have been either met or addressed.



	G_1	G_2	D_1 or D_2	*L_1 (ft.)
High Volume (Commercial, Industrial)	±3%	±5%	±3%	40
Low Volume (Commercial, Industrial)	±5%	±8%	±6%	40
Residential	±8%	±15%	Veh. Clear.	10

* For driveways with restrictive sight distances, it is often desirable to have L_1 equal to the maximum length of the design vehicle but not less than the values indicated in the table. For certain combinations of grades where no sight distance geometric or operational constraints exist, it may be possible to justify values of L_1 that are less than those in the table.

Source: Williams, Fambro, and Stover, TTI 990-2, p.19

EXHIBIT 2-16 Recommended vertical geometry limits in TTI report

Guidelines were recommended that allow designs to meet minimum safety and operational criteria. In addition to the design guidelines, the report discusses various elements that should be considered in formulating a design that includes site characteristics, functional requirements and design vehicles. Based on these factors, requirements for maximum and minimum driveway grades and lengths of grades were established. In addition, a procedural framework for implementation in design and analysis was presented.

Several noteworthy instances of trains striking low-ground-clearance vehicles that had become lodged or hung up at high-profile rail-highway grade crossings influenced Eck and Kang (*1991*) to examine the problem. A similar hang-up phenomenon can occur at the grade breaks associated with driveway entrances, although the consequences are rarely as severe.

Eck and Kang concluded that it is generally difficult to determine from crash data which incidents are the result of low-clearance vehicles becoming lodged on vertical geometry. Even though hard data were lacking, the problem was believed to be significant. A regional safety director for a nationwide trucking company that transports automobiles noted that his large fleet experienced 50 to 60 hang-up incidents per month, including grade crossings, driveway entrances and pavement crowns. Because of the lack of data on low-clearance vehicle incidents, Eck and Kang (*1991*) collected vehicle classification data on an Interstate highway in West Virginia. It was not unusual to find ground clearances of less than 6 inches for trucks with wheelbases in excess of 30 ft. Low-clearance trucks accounted for 0.8% of the traffic stream and about 5.7% of all trucks. These data did not include car and pickup-truck with trailer combinations that were also identified as being susceptible to hanging up at grade breaks. These accounted for 1.1% of the total volume in the classification count. It was concluded that while low-clearance vehicles are not a significant proportion of the traffic stream (about 2%), they do occur with enough frequency to warrant consideration by roadway designers and traffic engineers.

Interviews with truck drivers were conducted at weigh stations, rest areas, and interchange ramps on Interstate highways. Virtually every driver interviewed had either personally experienced a hang-up or knew someone who had. While these were over-the-road drivers, the specific problems they described occurred at driveways and rail-highway grade crossings on local roads, typically near a pick-up or drop-off point. The researchers identified double-drop equipment trailers, automobile transporters, double-drop van trailers and car and pick-up truck with trailer combinations as being particularly prone to hang-ups.

Exhibit 2-17 shows one example of the design recommendations produced by this work (*Eck and Kang*, *1992*).

EXHIBIT 2-17 Minimum length of Type-II crest vertical curve to accommodate low-clearance vehicle

Algebraic Difference (%)	Curve Length ft(m)
1	4 (1.2)
2	8 (2.4)
3	12 (3.7)
4	16 (4.9)
5	20 (6.1)
6	24 (7.3)
7	28 (8.5)
8	32 (9.8)
9	35 (10.7)
10	39 (11.9)

Source: Eck and Kang, TRR 1356

French, Clawson and Eck (*2003*) noted that the existing AASHTO design vehicles were essentially two dimensional representations in that they do not provide any ground clearance information, and their literature search did not produce design vehicle dimensions for vehicles prone to hang-up. (In addition to the low-bed equipment trailers, automobile transporters, double drop trailers and car/truck with trailer combinations identified in previous work, they identified recreational vehicles, rear-load garbage trucks, articulated beverage trucks, and certain transit buses as being susceptible to hanging up.) They reviewed manufacturer's data and made direct measurements to obtain wheelbase, overhang, and ground clearance dimensions for a sample of vehicles. Then they tested candidate vehicle dimensions on sample profiles with their previously-developed HANGUP software. The output revealed which vehicles would hang up on a given profile. By analyzing these plots and using engineering judgment, they developed design vehicle dimensions for 17 vehicle types.

The Transportation Research Institute at Oregon State University (ODOT, 1998; *Hodgson, 1999*) examined vehicle speeds at driveways. Vehicle speed data for both left and right turns into driveways were collected at eight different locations. Speeds were measured with pedestrians present and not present. Speeds were measured when the vehicles were approximately halfway through the turning maneuver, i.e., at an angle of approximately 45^{O} from the alignment of the street. Driveways were two and three lanes with widths ranging from slightly more than 30 ft for a two-lane driveway to 50 ft for a three-lane driveway. All through-roadway cross slopes were between 4.8 and 6.0%. Driveways had positive gradients ranging from 2 to 9.5%. Measurements made when no pedestrians were present indicated a fairly strong relationship between grade break at the gutter and vehicle speed. Speeds ranged from a high of about 14 mph for a grade break of slightly more than 6% to as low as about 3 mph for an approximately 17% grade break. Average speeds ranged from about 11 mph for a grade break of about 6% to about 7 mph for a 17% grade break. The vehicle types involved are unknown.

A New Jersey DOT-sponsored study (*Iqbal et al., 2001*) used a simulation model to determine permissible grades on driveways. The primary concern in the study appeared to be driveway speed as related to crashes on the mainline roadway. Field measurements (front and rear overhang, wheelbases and associated ground clearances) were taken of 60 automobiles, 23 semi-trailer trucks and 5 single-unit trucks. Bus measurements were acquired from manufacturers' websites. The report did not indicate where the measurements were taken, either in terms of geographic area or specific environment (e.g., types of roadway or parking lot). Similarly, the specific types of vehicles in terms of whether automobiles included passenger cars, SUV's and pick-up trucks or whether the trucks included automobile transporters, rear-load garbage trucks or articulated beverage trucks are not known. Based on data presented in the appendix of their report, it appears that low-clearance vehicles were not included in the sample, since the lowest reported ground clearance for trucks was one foot. The trucks included in the database had higher ground clearances than most of the automobiles examined.

It was stated that "The conditions of design for each situation will determine the allowable grades to be used for the driveway, which may exceed the suggested guidelines from the ITE publication." Allowable grades were dependent on vehicle type, length of grade, and speed of the vehicle entering the grade. It was acknowledged that the limitation to intersecting grades is based on the approach/departure and crossover angles of the design vehicle. The study attempted to incorporate the effects of the dynamics of vehicle suspensions, applying a 75% factor to the measured clearances. The basis for this adjustment was not presented. It was stated that "the crossover, approach and departure angles of a moving vehicle, is [sic] significantly different from those of a stopped vehicle." The examples presented in the report addressed vertical alignment of the driveway proper, and did not address the geometry of the driveway-roadway interface or of the complicating factor of additional grade breaks created by a sidewalk parallel to the mainline roadway.

One group of researchers used both simulations and field measurements based on the International Roughness Index to evaluate the profiles of six intersections of primary with secondary roadways (*Movassaghi et al., 1994*). The profiles of two of the six had similarities with commonly-seen profiles of driveways at the edge of roadways. The researchers concluded that intersection profile roughness was affected by both the curve parameters and by elevation differences.

Research on Collisions and Conflicts

This section reviews the literature on bicycle, pedestrian, and motor vehicle crash experience at driveways. It also presents findings from studies about which a part has some application to driveway crash experience.

Research on Bicycle Collisions

A study of all police-reported bicycle collisions in Hawaii in a six-year period, from 1986 to 1991 found that motor vehicle drivers were at fault 83% of the time (*Kim and Li, 1996*). Motorists' main error was failure-to-yield, while bicyclists' errors included failure-to-yield, disregarding controls, and riding in the wrong direction. The authors noted that the results may be "affected by the quality of police-collected data".

An examination of six years of Washington state data (*Wessels, 1996*) produced 8,540 bicycle collision records for analysis. The analyst employed a modified Cross-Fisher bicycle collision classification system with 22 categories. Less than 6% of collisions involved a motor vehicle striking a bicyclist from behind. For all roads and for city streets, Collision Group C (a motorist entering or leaving the roadway at a mid-block location, back from driveway) accounted for less than 1% of crashes. Group F (motorist turning, bicyclist not) included 1.1% on all roads and 1.4% on city streets. Less than 0.5% of the crashes on roads or on city streets fell into the "motorist drive out from park" subgroup within Group G.

In a sample of 3000 bicycle-motor vehicle crashes drawn from six states, 33.7% occurred on local streets, 27.5% on county roads, and 26.1% were on US and state highways. For all of the bicycle collisions, 1.7% occurred at alleys and driveways (*Hunter et al., 1996*).

Research on Pedestrian Collisions

Although different sources present slightly different figures, there is no disagreement that a sizeable number of non-motorists are injured or killed by collisions with motor vehicles. One source stated that in the United States, about 5,500 pedestrians are killed and 90,000 are injured each year, with pedestrians constituting 14% the traffic fatalities, and up to 40% or more in some larger urban areas (*Stutts et al., 1996*). Another source stated that while 8.6% of all trips are made on foot, pedestrians constitute 11.4% of US traffic fatalities. At 20.1 deaths per hundred million miles walked, compared to 1.3 deaths per hundred million miles of travel for drivers and their passengers, pedestrians are killed at a rate that is 15 times greater than that of motorists (*Ernst, 1998*). Two often-cited factors in pedestrian accidents are alcohol and vehicle speed.

Alcohol impairment may be as serious a problem for pedestrians as it is for motor-vehicle drivers, although fatal crash data from 2000 suggests the problem may be on the decline. A blood-alcohol concentration (BAC) of 0.10 or more was reported in 37% to 44% of pedestrians killed from 1980 through 1987 (*AASHTO website, 2004*).

Vehicle speed affects pedestrians and other non-motorized users. At higher speeds, motorists need more distance and time to see and react to what is ahead, whether it be another vehicle, a bicyclist, or a pedestrian. When a pedestrian is struck, vehicle speed is of special concern. The Department of Transport (United Kingdom, UK) reported the following relationship between vehicle speed and chances of struck pedestrian being killed (*AASHTO website, 2004*).

Vehicle Speed	Probability of fatal injury
40 mph (64.4 km/h)	85%
30 mph (48.3 km/h)	45%
20 mph (32.2 km/h)	5%

Stutts et al. (*1996*) took a sample of approximately 830 pedestrian crashes, stratified to reflect community size, from six states. For each crash, a copy of the police report and the state computerized crash and roadway data were obtained. After a review, each crash was coded. About 1/3 were intersection-related (alleys and driveways were called intersections only when controlled by a traffic signal).

When the police report indicated the crash occurred on private property, a description (e.g., parking lot, driveway, and so forth) was also coded. Although most of the crashes in each crash-type category were on public roadways, three types (not in road, backing vehicle, and driverless vehicle) tended to occur on private property.

The original NHTSA typology based on 37 pedestrian crash types was expanded to 61 types for this study (see Exhibit 2-18), allowing a better understanding of the specific circumstances contributing to particular type crashes, especially in the "other-weird" category, which otherwise was undefined. The typology was expanded to include more detailed roadway and locational information, which would help develop effective countermeasures against specific crash types. For example, analysis indicated that nearly one-half of backing-vehicle crashes occurred in parking lots and 13% in driveways or alleys, a finding not available from the crash typing process alone.

The "not in road" is a mixed category, since it includes pedestrians standing at or near a curb. For those crashes involving pedestrians not in the roadway (under 9%), usually both the pedestrian and the vehicle were off the road: 47% in parking lots, and another 15% in driveways or the sidewalk that crossed a driveway (Type 620). A small percentage of cases involved a vehicle leaving the road and striking a pedestrian (Type 621), or a pedestrian at or near the curb (Type 610 or 611) waiting to cross.

Among backing-vehicle crashes, 17% were on driveways or sidewalks. Driveways were the site of 35% of driverless-vehicle crashes.

EXHIBIT 2-18 Distribution of pedestrian crash types

Distribution of Pedestrian Crash Types

Crash Type	N	Percent*
Special Circumstances	22	0.4
110 Commercial bus-related	22	0.4
120 School bus-related	40	0.8
130 Vendor/ice-cream truck	16	0.3
140 Mailbox-related	33	0.7
150 Exiting/entering parked vehicle	133	2.6
Vehicle Specific		
210 Driverless vehicle - ped. was driver	80	1.6
211 Driverless vehicle - ped. not driver	24	0.5
220 Backing vehicle	351	6.9
230 Hot pursuit	5	0.1
	460	9.1
Disabled/Emergency Veh-Related		
310 Walking to/from disabled vehicle	9	0.2
320 Disabled vehicle related	105	2.1
330 Emergency/police veh. related	10	0.2
	124	2.4
Working/Playing in Roadway		
410 Working on roadway	69	1.4
420 Play vehicle-related	35	0.7
430 Playing in roadway	48	0.9
	152	3.0
Walking along Road/ Crossing Expressway		
510 Hitchhiking	15	0.3
520 Expressway crossing	25	0.5
531 Walking with traffic, struck from behind	257	5.1
532 Walking against traffic, struck from behind	76	1.5
533 Walking with traffic, struck from front	5	0.1
534 Walking against traffic, struck from front	7	0.1
539 Walking along rd. - side unknown	15	0.3
	400	7.9
Not in Road		
610 Waiting to cross at/near curb - veh. turning	18	0.4
611 Waiting to cross at/near curb - veh. not turning	14	0.3
620 Ped. and veh. not in roadway	346	6.8
621 Ped. not in roadway, veh. left roadway	58	1.1
	436	8.6

Crash Type	N	Percent
Intersection-Related		
710 Multiple threat at intersection	64	1.3
720 Vehicle turn/merge	497	9.8
730 Intersection dash	363	7.2
740 Trapped	41	0.8
750 Ped. walks into veh., unknown	18	0.4
751 Ped. walks into veh., instantaneously	13	0.3
752 Ped. walks into veh., non-instantaneously	11	0.2
760 Driver violation, intersection	259	5.1
790 Intersection - Other	109	2.1
791 Standing in road at intersection	14	0.3
792 Instantaneous step into road	57	1.1
793 Misjudged gap when crossing	25	0.5
794 Walking in road prior to impact	159	3.1
	1630	32.1
Midblock		
810 Multiple threat-midblock	46	0.9
821 Dart-out, first half	176	3.5
822 Dart-out, second half	50	1.0
829 Dart-out, can't specify	6	0.1
830 Midblock dash	442	8.7
840 Ped. walks into vehicle - unknown	34	0.7
841 Ped. walks into veh. - instantaneously	21	0.4
842 Ped. walks into veh. - non-instantaneously	18	0.4
890 Midblock - Other	209	4.1
891 Standing in road - midblock	47	0.9
892 Instantaneous step into road-midblock	60	1.2
893 Misjudged gap when crossing - midblock	35	0.7
894 Walking in road - midblock	197	3.9
	1341	26.4
Other or Inadequate Information		
910 Other - weird	85	1.7
911 Lying in road	22	0.4
912 Suicide	6	0.1
913 Assault with vehicle	55	1.1
914 Domestic/dispute	76	1.5
915 Sitting/leaning/clinging to vehicle	40	0.8
916 Result of vehicle-vehicle crash	61	1.2
917 Result of vehicle-object crash	25	0.5
920 Inadequate information	27	0.5
	397	7.8
All Crashes	5,073	

* Column percents

Source: Stutts et al., TRR 1538, Tab. 1, p.70

Exhibit 2-19 (Table 3) shows the distribution of pedestrian accident severity. Of those crashes not-in-road, 28.3% were either injury-A or fatal. Exhibit 2-20 (Table 7) shows, for the major crash-type subgroups, the pedestrian location. Bus-related, intersection-related (including vehicle-turning, intersection-dash, driver-violation, and other crash types), and midblock crashes (including darts and dashes and other crash types) usually involved a pedestrian being struck in the travel lane. Among the not-in-road crashes, 50% were in parking lots, 17% on sidewalks, and 15% in alleys or driveways. For backing-vehicle crashes, 45% were in parking lots and 13% in alleys or driveways (*Stutts et al., 1996*). Considering all of the pedestrian crashes, 3% were at alleys and driveways.

EXHIBIT 2-19 Pedestrian crash types

Pedestrian Crash Types by Pedestrian Injury Severity

Pedestrian Crash Type Subgroup	Injury Severity*: No Injury	C	B	A	Fatal
Bus related	2.3	25.0	45.5	22.7	4.5
Other vehicle-specific	0.0	24.7	43.8	25.8	5.6
Driverless vehicle	1.4	24.3	36.5	35.1	2.7
Backing vehicle	2.4	39.2	35.8	20.8	1.7
Disabled vehicle related	2.5	24.2	31.7	32.5	9.2
Working/playing in road	3.5	32.2	37.1	25.9	1.4
Walking along roadway	1.5	23.9	34.3	27.2	13.2
Not in road	3.3	31.9	36.4	24.7	3.6
Vehicle turning at intersection	2.4	44.6	34.5	16.6	1.8
Intersection dash	3.4	25.4	37.6	29.4	4.2
Driver violation at intersection	2.4	32.2	37.6	22.7	5.1
Other intersection	3.0	27.2	33.6	30.8	5.4
Midblock dart/dash	2.4	23.2	38.8	30.0	5.6
Other midblock	1.5	23.0	28.7	35.7	11.1
Miscellaneous	3.8	26.5	36.8	25.7	7.3
All Crashes	2.5	28.7	35.3	27.4	6.1

*Row percents. Cases with unknown injury severity excluded.

Source: Stutts et al., TRR 1538, Tab.3, p.71

EXHIBIT 2-20 Pedestrian crash locations

Pedestrian Crash Types by Detailed Pedestrian Location

Pedestrian Crash Type Subgroup	Pedestrian Location*: Travel Lane	Shoulder or Edge of Lane	Side-walk	Alley, Drive-way	Parking Lot	Other
Bus related	97.7	2.3	0.0	0.0	0.0	0.0
Other vehicle-specific	76.6	9.6	0.0	0.0	3.2	10.6
Driverless vehicle	26.2	5.8	1.0	20.4	36.9	9.7
Backing vehicle	22.6	2.6	6.3	13.1	44.9	10.6
Disabled vehicle related	58.1	30.7	0.0	1.6	1.6	8.1
Working/playing in road	79.0	7.9	0.0	1.3	1.3	10.5
Walking along roadway	53.0	41.2	0.3	0.3	0.0	5.2
Not in road	3.9	5.5	16.7	14.9	49.8	9.2
Vehicle turning at intersection	97.2	1.2	1.0	0.0	0.0	1.6
Intersection dash	100.0	0.0	0.0	0.0	0.0	0.0
Driver violation at intersection	98.5	0.8	0.0	0.0	0.0	0.8
Other intersection	98.8	0.2	0.0	0.0	0.0	0.0
Midblock dart/dash	99.3	0.0	0.0	0.3	0.0	0.4
Other midblock	96.7	1.2	0.0	0.0	0.5	1.6
Miscellaneous	50.1	10.4	4.7	3.1	13.0	18.7
All Crashes	74.2	6.4	2.3	3.0	9.3	4.8

*Row percents. Cases with unknown pedestrian location excluded.

Source: Stutts et al., TRR 1538, Tab. 7, p.73

Clifton and Kreamer-Fults (*2006*) stated that previous research had shown that improper pedestrian behaviors on the part of children led to high involvement in pedestrian-vehicle crashes, but there was little research investigating relationships between schools and pedestrian crashes. Analyzing Baltimore, Maryland pedestrian-vehicular crash relationships with schools and the physical attributes, they found that crash occurrence and severity decreased with the presence of a driveway, but increased with the presence of recreational facilities.

Research on Motorists Yielding to Pedestrians

One of the many concerns that have been expressed about driveway operations is that some motorists do not yield the right-of-way to pedestrians.

In the late 1990s, Oregon researchers examined the effects of access on pedestrians, bicyclists, and transit users, including conflicts between vehicles and pedestrians or bicyclists at driveways (ODOT, 1998; *Hodgson, 1999*). They recorded the speeds of vehicles turning into driveways for a few different driveway shapes, widths, and radii. Making 14 comparisons of the vehicular speeds from eight sites, they concluded that the presence of pedestrians did not alter the average vehicular speed of vehicles turning into driveways (*Hodgson, 1999*). They also found that at locations where there was a separate right-turn lane, the average speed of vehicles entering the driveway was less than at locations without the right turn lane, but they also included the caveat against drawing a general conclusion from this. They were unable to draw conclusions about similar effects on bicyclists, because the effort did not produce enough data.

One study tested treatments that might affect motorists' propensity to yield the right-of-way to pedestrians (*Fitzpatrick, 2006*). Field studies were conducted to test the effectiveness of a number of different treatments. The field studies supported what had been found in previous literature, that red signal or beacon devices were more effective than the other devices they tested (between 90 and 100% motorist compliance at all study sites).

During data analysis, the researchers noticed that for the same treatment, motorists' compliance rates varied considerably by site. The researchers hypothesized that other elements were influencing the effectiveness of a particular treatment. The example given was that installing an in-street crossing sign on a collector street with lower speed and narrower width would bring about greater compliance than if installed on a wider, higher-speed arterial. They qualitatively and statistically analyzed the data to identify factors affecting driver compliance. The posted speed limit and the number of lanes crossed proved to be statistically significant in predicting whether a treatment led to increased yielding to pedestrians, and in explaining part of the wide range of responses to a treatment.

When considering the number of lanes, a median refuge island was the only treatment with statistically different compliance values. It should be noted that from an inspection of Figure 25 in that report (*Fitzpatrick, 2006*), it does not appear that the variety of treatments tested were evenly distributed across the three number-of-lane categories (2-lane, 4-lane, 6-lane). Only two treatments were listed as having been observed on six-lane roadways, and these two treatments were those that also performed worse at the two- and the four-lane sites.

Research on Driveway Collisions

Box studied the relationships among land uses, volumes, and accidents in which driveways were an influencing factor (*Box, May 1969; Box, July 1969*). Because 83% of all driveway accidents in Skokie, IL, occurred on the major traffic streets, a preliminary study began with two years of crash data from 39.7 mi of these routes. Left-turns were involved in 60% of all and 75% of the injury accidents.

Number of crashes per year for:

service stations	0.15
other commercial and industrial uses	0.27
alleys	0.05
residential driveways	0.02

Driveways on 39.7 mi of major traffic routes experienced an average of 0.13 crashes per year, but for the 569 residential driveways on the major streets, the rate was 0.02 crashes per year. Routes with barrier medians had 0.02 accidents per driveway per year, as compared to other routes that had 0.17 – a ratio of about 1 to 8.

An expanded study covered five years of data. The data showed that 11% of all reported crashes involved driveway movements. When segregated by street function, it was found that driveways were a factor in 12% of the crashes on major streets and 9% of those on residential streets. With a greatly expanded data set, the annual number of crashes at service stations was found to be 0.19, and for all commercial driveways it was 0.33 per year. There was a general trend that as traffic volume routes increased, the number of accidents per commercial driveway increased.

Of the 407 pedestrian and bicycle rider accidents during the five-year period, 3% involved driveways, most often with a motor vehicle leaving the establishment. Box made it a point to note that these data were not from a city with a large central business district.

Extremely wide (100 to 120 ft) access openings had four times the accident frequency of shorter openings. At service stations, the greater number of driveways per station, the greater number of accidents (*Box, July 1969*).

In a review of literature, Azzeh et al. (*1975*) referenced a study of the Indiana data showing that 6.8% of all accidents were reported as driveway accidents. National Safety Council (NSC) statistics that showed driveway vehicles were involved in 4.9% of urban accidents and 6% of rural accidents. In urban areas, the vehicle leaving the driveway was involved in 63% of the crashes, while in rural settings, the vehicle entering the driveway was involved in 58% of the crashes. Two other cited studies suggested that the NSC figure was low: one study found driveway maneuvers were involved in 11% of crashes, and the other found this in 13% of rural accidents. Box was credited with having performed the most complete study of driveway crashes by maneuver and collision type. The literature review presented the data shown in Exhibit 2-21, taken from the earlier study by Box.

Maneuver	Turn	Collision	Percent of Total Driveway Accidents
Entering	Left	Rear-end	26
Leaving	Left	Right-angle	24
Entering	Left	Head-on angle	15
Entering	Right	Rear-end	12
Leaving	Right	Right-angle	7
Leaving	Right	All other	8
Leaving	Left	All other	3
Entering	Right	All other	3
Entering	Left	All other	2
			100

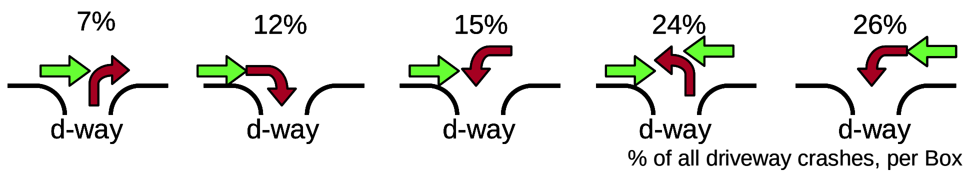


EXHIBIT 2-21 Driveway crashes by maneuver

Although the a series of research publications from the 1970s with titles such as "Evaluation of Factors Influencing Driveway Accidents" (*McGuirk and Satterly, 1976*) suggests a trove of pertinent information, the main focus was on the safety effects of driveway spacing. They found driveway accidents to account for 13.95% of the total number of accidents in four years on 100 roadway sections. Of these driveway crashes, left turn movements, in or out, were present in 64.6% of all and in 76.0% of injury crashes. When the average spacing between adjacent driveways and between a driveway and an adjacent intersection leg increased, the driveway accident rate on that road section trended downward.

A review of Texas' driveway related accidents between 1975 and 1977 (*Richards, 1980*) found that 93% of all driveway-related accidents occurred in cities and towns. About two-thirds of the crashes involved a vehicle leaving the driveway and less than one-third involved a vehicle entering the driveway.

Exhibit 2-22 from this report shows that some accident types, such as angle crashes involving either right turn exit or left turn exit driveway vehicles, constituted the about the same percent of total driveway-related crashes on both the local (city, county) roads and on the state-maintained roads.

EXHIBIT 2-22 Driveway-related crashes in Texas

Accident type	Maneuver	City, County roads Annual Accidents	City, County roads Percent of Total	State-maintained roads Annual Accidents	State-maintained roads Percent of Total
Rear-end	Right Turn Entry	3,925	9	-	-
	Rt-Turn Entry or Exit	-	-	2,800	12
	Left Turn Entry	3,490	8	-	-
	Lt-Turn Entry or Exit	-	-	2,550	11
	All Others	-	-	4,050	18
Head-on	Left Turn Entry	3,925	9	2,800	12
Angle	Right Turn Exit	3,050	7	1,900	8
	Left Turn Exit	7,410	17	3,750	17
	Backing Exit	6,540	15	-	-
	All Others	-	-	1,450	7
One Car	Backing Exit	8,720	20	-	-
Other	--	6,540	15	1,850	8
Totals		43,600	100	22,700	100

Source: Richards, TTI 5183-2

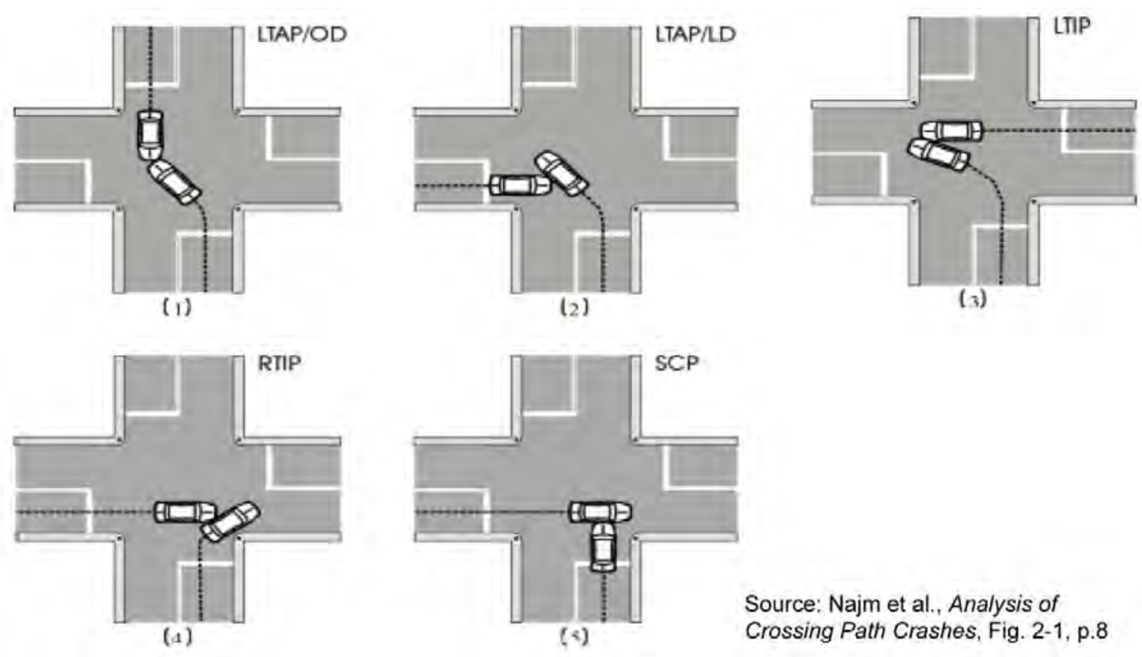
Of the crashes on city or county roads, approximately 17% involved a vehicle being struck from the rear while attempting to enter a driveway, while 35% involved a vehicle backing from a driveway. At least 1,000 accidents each year involving a vehicle backing from a driveway and striking another vehicle stopped at a controlled intersection. Backing accidents were less common in large cities.

Najm et al. made use of the 1998 National Automotive Sampling System/General Estimates System (GES) to study the frequency, matter of collision, and location of crossing path crashes, along with the pre-crash scenarios. To be coded as an intersection crash with this typology, the first harmful had to occur within the physical limits of the intersection (*Najm et al., 2001*). To receive an intersection-related coding, the first harmful event must occur in a vaguely-described area near the physical intersection, and be related to motion through the intersection. The "Driveway, Alley Access," "Ramp," and "Grade Crossing" codes indicate that the crossing path crash was related to motion through a junction between these and a roadway. Crossing path crashes were defined as "those that involve the type of traffic conflict where one moving vehicle cuts across the path of another, when they were initially approaching from either lateral or opposite directions, in such a way that they collided at or near a junction". The study also included vehicle-pedestrian and vehicle-pedalcyclist collisions. Exhibit 2-23 graphically explains the codes used to describe the combinations of crossing path crash vehicle orientations.

Exhibit 2-24 shows, for all vehicle types, the proportion of crossing path crashes in the various relation-to-junction categories, stratified by the crossing path pattern. About 9% of all crossing path crashes involved a vehicle turning right out of the driveway. Most of the crossing path crashes involved a left-turn.

Exhibit 2-25 indicates that about 19% of pedalcyclist and 6% of pedestrian collisions had been coded as driveway. Exhibit 2-26 shows that for crashes at locations with no controls (such as it likely to be the case at driveways) involving either light vehicles or commercial vehicles, obstructed vision was a factor. Pedestrian and pedalcyclist collisions were more likely to be fatal at intersections than at driveways.

Rawlings and Gattis (*2008*) examined over 2,000 accident reports from one small city for one year to identify which crashes were driveway-related. Driveway-related was defined as a collision that occurred either directly or indirectly due to the operation of a driveway. They found that the single highest proportions of crashes involved left-turn egress. Almost 1/6 of the crashes involved vehicles backing from a driveway. Over 1/6 of the crashes involved maneuvers in a TWLTL that possibly would not have occurred had a restrictive (raised or depressed) median, with or without left-turn lanes, been in place. Exhibit 2-27 compares their findings with those of previous studies.



Source: Najm et al., *Analysis of Crossing Path Crashes*, Fig. 2-1, p.8

EXHIBIT 2-23 Explanation of codes to describe crash patterns

Relation to Junction		Crossing Path (CP) Crash Scenarios							
		LTAP/OD	LTAP/LD	LTIP	RTIP	SCP	Other	All CP	% All CP
Non-Interchange	Non-Junction	4,000	*	1,000		2,000	2,000	9,000	0.5%
	Intersection	357,000	204,000	57,000	57,000	486,000	112,000	1,274,000	**74.1%**
	Intersection-Related	4,000	6,000	4,000	4,000	2,000	30,000	50,000	**2.9%**
	Driveway, Alley, etc.	101,000	124,000	35,000	34,000	21,000	46,000	360,000	**20.9%**
	Ramp	*		*	*	*		1,000	
	Grade Crossing	*					*	*	
	Bridge	*	*		*	*		1,000	
	Other	1,000		1,000	1,000		1,000	3,000	0.2%
Interchange	Non-Junction								
	Intersection	5,000	4,0(	[illegible]	[illegible]	4,000	2,000	17,000	1.0%
	Intersection-Related	1,000	[illegible]	[illegible]	[illegible]	*	*	2,000	0.1%
	Driveway, Alley, etc.				1,000	*	*	1,000	0.1%
	Ramp	*	*	1,000	*	*	*	2,000	0.1%
	Bridge	*						*	
	Other	*			*		*	*	
	Total	472,000	339,000	102,000	99,000	514,000	194,000	1,720,000	100.0%
	% Total	27.5%	19.7%	5.9%	5.7%	29.9%	11.3%	100.0%	

Source: Najm et al., *Analysis of Crossing Path Crashes*, Fig. 2-1, p.8

- Numbers in cells were rounded to the nearest 1,000.
- Empty cells refer to scenarios that had no crashes in the 1998 GES sample.
- The symbol * represents crash frequencies below 500.

Source: Najm et al., *Analysis of Crossing Path Crashes*, Tab. 3-1, p.10

EXHIBIT 2-24 Proportion of crossing path crashes in various relation-to-junction categories

Relation to Junction		Pedalcyclist	Pedestrian	Both
Non-Interchange	Non-Junction	12,000	39,000	52,000
	Intersection	33,000	25,000	58,000
	Intersection-Related	1,000	3,000	4,000
	Driveway	11,000	4,000	15,000
	Ramp		*	*
	Grade Crossing			
	Bridge	*	*	*
	Other		*	*
Interchange	Non-Junction		*	*
	Intersection	*	*	*
	Intersection-Related	*		*
	Driveway			
	Ramp	*	*	*
	Bridge			
	Other			
	Total	58,000	72,000	130,000

- Numbers in cells were rounded to the nearest 1,000.
- Empty cells refer to scenarios that had no crashes in the 1998 GES sample.
- The symbol * represents crash frequencies below 500.

Source: Najm et al., *Analysis of Crossing Path Crashes*, Tab. 5-1, p.23

EXHIBIT 2-25 Non-interchange locations of pedalcyclist and pedestrian crashes

Vision Obstruction and Driver Distraction Statistics for *Light* Vehicles Involved in Crossing Path Crashes at Driveways (Based on 1998 GES)

TCD	Factor	LTAP/OD		LTAP/LD		LTIP		RTIP		SCP	Other
		Turning	Straight	Turning	Straight	Turning	Straight	Turning	Straight		
Signal	Vision Obstructed	12.6%	1.3%	9.9%	4.8%					12.4%	0.6%
	Driver Distracted	5.4%		5.6%	7.4%						
Stop Sign	Vision Obstructed			23.3%	8.8%	20.0%	15.7%			5.2%	3.6%
	Driver Distracted			0.7%		7.3%				1.5%	6.2%
No Controls	Vision Obstructed	8.2%	3.2%	15.8%	5.1%	1.8%	0.7%	7.1%	1.1%	4.2%	6.3%
	Driver Distracted	4.5%	0.1%	4.5%	0.3%	2.5%		1.2%	0.9%	2.6%	0.7%

- Empty cells refer to scenarios that had no crashes in the 1998 GES sample.

Vision Obstruction and Driver Distraction Statistics for *Commercial* Vehicles Involved in Crossing Path Crashes at Intersections (Based on 1998 GES)

TCD	Factor	LTAP/OD		LTAP/LD		LTIP		RTIP		SCP	Other
		Turning	Straight	Turning	Straight	Turning	Straight	Turning	Straight		
Signal	Vision Obstructed		0.4%							0.5%	2.6%
	Driver Distracted	0.2%		0.2%	3.4%					0.4%	3.3%
Stop Sign	Vision Obstructed	1.9%		13.2%	1.6%	33.5%	0.6%	0.6%		1.9%	0.5%
	Driver Distracted	1.9%		0.4%					0.9%	1.3%	0.8%
No Controls	Vision Obstructed			38.9%	7.1%					39.7%	6.2%
	Driver Distracted	0.3%			8.3%						0.5%

- Empty cells refer to scenarios that had no crashes in the 1998 GES sample.

Source: Najm et al., *Analysis of Crossing Path Crashes*, Tab. F-8, 9, p. F-8

EXHIBIT 2-26 Percent of driveway crashes in which obstructed vision was a factor

EXHIBIT 2-27 Comparing driveway-related collision studies

Percent of all with attribute	Skokie	Indiana	Texas	Arkansas	Springdale
urban that are driveway-related	11	14	15	13	19
occurred at commercial sites	75	72	-	-	73
occurred at restaurants	16	-	-	-	17
occurred at service stations	16	-	-	-	10
involved left turns	60	65	-	-	63
resulted in injury	31	14	11	38	?
involved pedestrians or bicyclists	4	-	-	1	1

Source: Rawlings and Gattis, TRB Paper 08-0710

Research on Crash Data Errors

Users of crash data should be well aware that the data is not without its faults. There are a number of potential sources of error from the time crash information is initially recorded by the investigator at the scene until information is stored in a crash record database.

A study was performed to ascertain how much variability resulted when 12 people from a group of safety professionals, transportation planners and engineers, and bicycle and pedestrian coordinators were given the same set of 13 pedestrian and 12 bicycle collision reports, a user's manual and software, and then were asked to encode the 25 crash reports. After the coding was completed, the input was compared with the "correct" answers, as previously determined by the project team. The data entries that were correctly coded up until the last decision was made were said to be within one level of correct. Entries that were more than one level away from being correct were considered to be more major mistakes. The bicycle crashes were 88% correct and the pedestrian crashes were 76% correct. Among the bicycle crashes, 92% were within one level of error, while 89% of the pedestrian crashes were. One of the bicycle and of the pedestrian reports proved to be especially problematic. The problematic bicycle collision was incorrectly coded by 33% as an overtaking collision, when in fact a motorist turning right into a driveway had collided with a bicyclist traveling the same direction, a turning collision. The problem pedestrian collision involved a driverless vehicle (*Harkey and Bloomberg, 2001*).

One study found that fewer than two-thirds of bicycle-motor vehicle crashes that were serious enough to require emergency room treatment were reported in the state crash files (*FHWA Course*).

While performing a detailed examination of over 2,000 collision reports from one small city for one year, Rawlings and Gattis (*2008*) were able to identify and code the specific pre-crash maneuver patterns associated with each collision. This level of detail enhanced the ability to correctly identify collisions that were related to the actual operation of a driveway, and would have gone unnoticed in a study of only summary data. It led to expanding the pool of accident-related crashes by 19% over the number in the agency database, and to removing 4% of the crashes from those that had been listed as driveway-related.

Guidelines

A review of guidelines from a period that spans close to a half-century develops at least a partial snapshot of the evolution of thinking about geometric design of driveways. Over the years, the depth and sophistication with which the issues are addressed has increased considerably.

The research team members reviewed a variety of guidelines. Topics commonly found in the guidelines include driveway width, radius (or flare) treatments and dimensions, vertical alignment, angle of intersection with the street, channelization, left turn controls, spacing, and corner clearance. It was less common to find content that addressed the number of driveways per property (which was often keyed to the amount of frontage), throat length, and building setback.

Some of the more comprehensive guidelines from among those reviewed include the American Association of State Highway Officials' (AASHO) 1959 informational guide (*AASHO, 1959*), multiple Institute of Transportation Engineers' (ITE) guidelines (*ITE, 1984; ITE, 1987; ITE, 1993*), Stover and

Koepke's (*2002*) *Transportation and Land Development*, the *Access Management Manual* (*Committee, 2003*) by the Transportation Research Board (TRB), and Florida's *Driveway Handbook* (*Systems, 2005*).

Newer guidelines incorporate criteria that, where the sidewalk and driveway cross, limit the sidewalk cross slope (or driveway grade) to 2%. The more recent driveway guidelines tend to address access management concepts such as increased corner clearances and spacing between driveways, left-turn provisions, street-like multi-lane driveways, and more on-site storage. This is in contrast to earlier documents showing much closer driveway spacings that are perhaps more typical of urban environments.

In addition to the guidelines, this section presents past practices found in the documents of a few state and local government agencies having authority over specific roadways. Unless one has access to either the people that formulated the agency policies or to their notes, one cannot know to what extent any set of policies was influenced by national publications from AASHTO or ITE, or policies from other agencies.

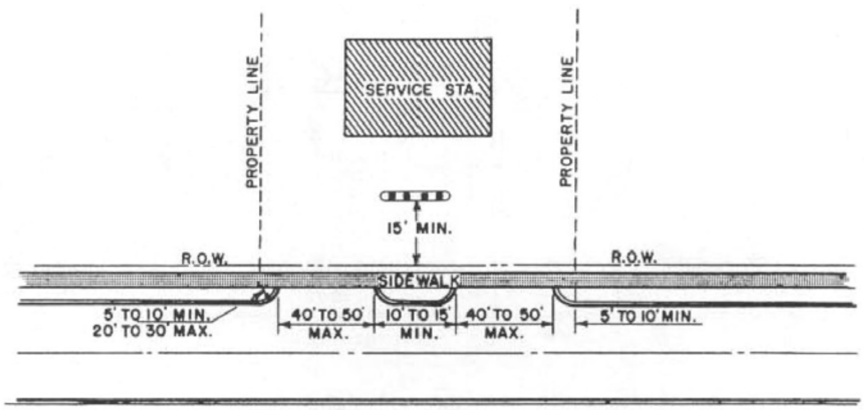
Guideline Caveats

A number of professional organizations and national groups have published recommended practices and guidelines for the geometric design of driveways. Guidelines often are consensus documents, representing the collective opinions of the committee members that prepare them. These opinions could be based on research findings, the experience that arises from accumulated observations, or beliefs arrived at from a mental conceptualization and analysis. Guidelines may also simply reflect practices that are generally accepted by a group or organization, and in this case could perhaps be characterized as the technical version of what sociologists refer to as folk wisdom.

It is not uncommon to read a recommended guideline or design practice, and to find no mention of a source that supports the guideline; in other words, the guideline is undocumented. Also, some may take lessons drawn from research conducted in a specific context, then apply the lessons outside of that context. For these or other reasons, a proposed or an accepted design practice may not be well-supported. On the other hand, a practice that has not been substantiated by research may still be sound.

The AASHO Guide

The Executive Committee of the American Association of State Highway Officials (AASHO) ordered the printing of *An Informational Guide for Preparing Private Driveway Regulations for Major Highways* in 1959 (*AASHO, 1959*). This document contains general principles and control dimensions for driveways. There were a number of illustrative sketches and examples offering definitions (3 figures), driveway profile controls (1 figure), and typical driveway plans and dimensions (12 figures). These typical plans were for service stations (5 figures), residential driveways (2 figures), commercial driveways (3), drive-in theaters (1 figure), and driveway groupings on a frontage road (1 figure). The following Exhibit 2-28 is one example.



DOUBLE DRIVEWAYS TO A MIDBLOCK SERVICE STATION — URBAN

Source: Am. Assn. of State Hwy. Officials, *An Informational Guide For Preparing Pvt. Driveway Regulations for Major Highways*, Fig. 14, p. 28, 1960, Washington, DC. Used by permission.

EXHIBIT 2-28 Example figure from 1960 driveway guide

The publication mentioned geometric controls such as driveway radius, angle, and sight distance. It stated that single driveways should be positioned at right angles to the roadway, and of that vertical curves should be flat enough so that the underside of passenger vehicles would not drag. Interestingly, it also suggested the following practice.

> “Where curbs are used along the roadway and sidewalks or provided or contemplated, the gradient of the driveway usually should fit the plane of the sidewalk. If the difference in elevation of the gutter and the sidewalk is such that this is not practical, in the sidewalk should be lowered to provide a suitable gradient for the driveway; in such case the surface of the sidewalk should be sloped gently from either side of the driveway.”

The guide addressed the location and the number of driveways, and acknowledged the need for separation between the driveway and adjacent tracts (i.e., the property line perpendicular to the roadway), with what it called the “edge clearance,” separation between two drives serving the same tract, and near-side corner clearance from signalized intersections. It used the term “buffer area” to describe "the border area along the frontage between the travel the way and the right-of-way line.”

Stover

Stover's work included a pair of recommended designs for auxiliary right turn lanes in advance of the driveway and three, one for a driveway without a median and another for a driveway with a median (*Stover, 1981*). Exhibit 2-29 shows the latter, with dimensions listed for an arterial speed of 40 mph.

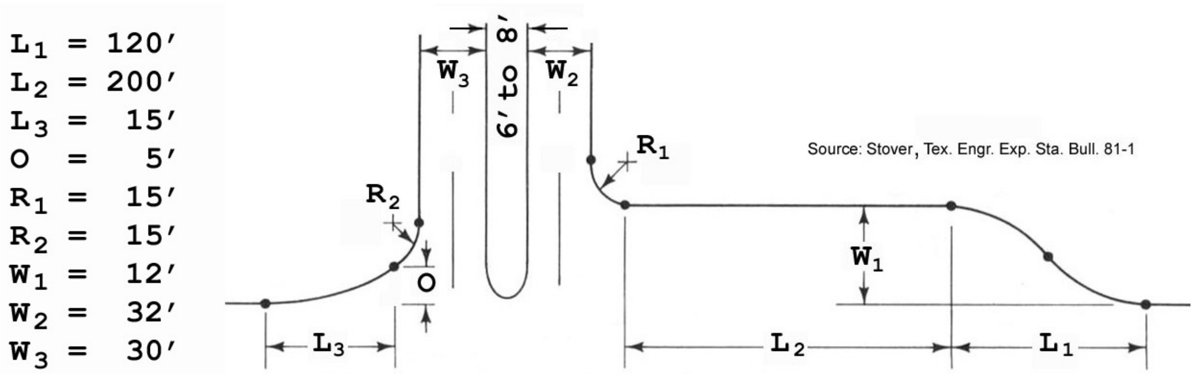


EXHIBIT 2-29 Recommended unsignalized driveway design with auxiliary right-turn lane

Box

Box (*March 1981*) suggested the following dimensions for commercial driveways (see Exhibit 2-30). For very high-volume driveways with two lanes in and two out, he suggested a median in order to reduce the uncontrolled width. To have landscaping, a minimum median width of 8 ft was suggested.

Box observed that developments that produce high traffic volumes usually need a channelized exit reservoir, along which there is no access to internal circulation roads or rows of parking. For the length of this reservoir (i.e., connection depth or throat length), he offered a rule-of-thumb of length in feet equal to the number of exiting vehicles turning left during the peak-hour. Box also stated that it may be desirable to observe queue lengths on the main roadway in order to determine how far back from a controlled intersection a driveway should be located (*Box, Feb. 1981*).

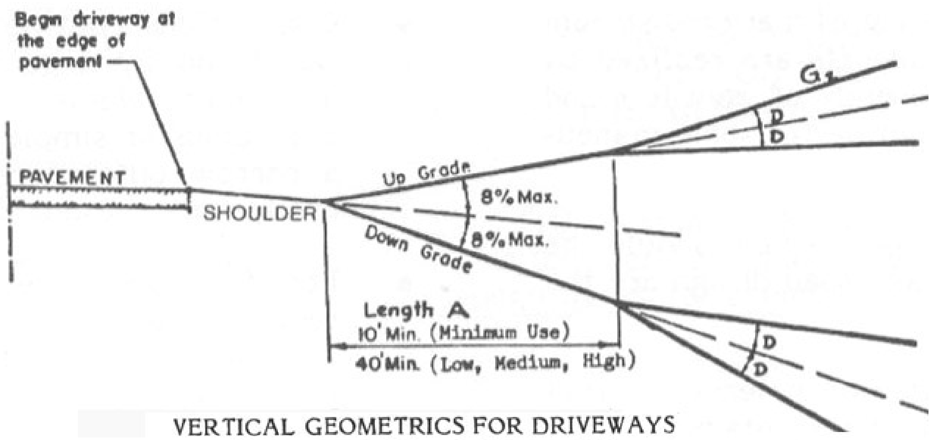
EXHIBIT 2-30 Suggested higher-volume driveway width and radius

	Standard	Moderate Volume	High Volume
Curb Radius	15 ft	15–25 ft	20–30 ft
Throat Width	30 ft	40-56 ft	2 @ 22 to 24 ft with 4-12 ft median

Source: Box, *Public Works*, Mar. 1981

FHWA Synthesis

The Federal Highway Administration's *Access Management for Streets and Highways* (*Flora and Keith, 1982*) addressed some driveway related topics. It included a table of recommended driveway Lane widths as a function of driveway offset and return radius, based on the previous work by Azzeh et al. It also recommended the vertical alignment controls shown in Exhibit 2-31.



VERTICAL GEOMETRICS FOR DRIVEWAYS

Recommended Grade Changes (D)

	ADT	Desirable	Maximum
Low Volume Driveway	(0-500)	+6 percent	Controlled by Vehicle Clearance
Medium Volume Driveway	(500-1500)	±3 percent	±6 percent
High Volume Driveway	(>1500)	0 percent	±3 Percent

Source: Flora and Keith, *Acc. Mgmt. for Sts. & Hwys.*, p.65

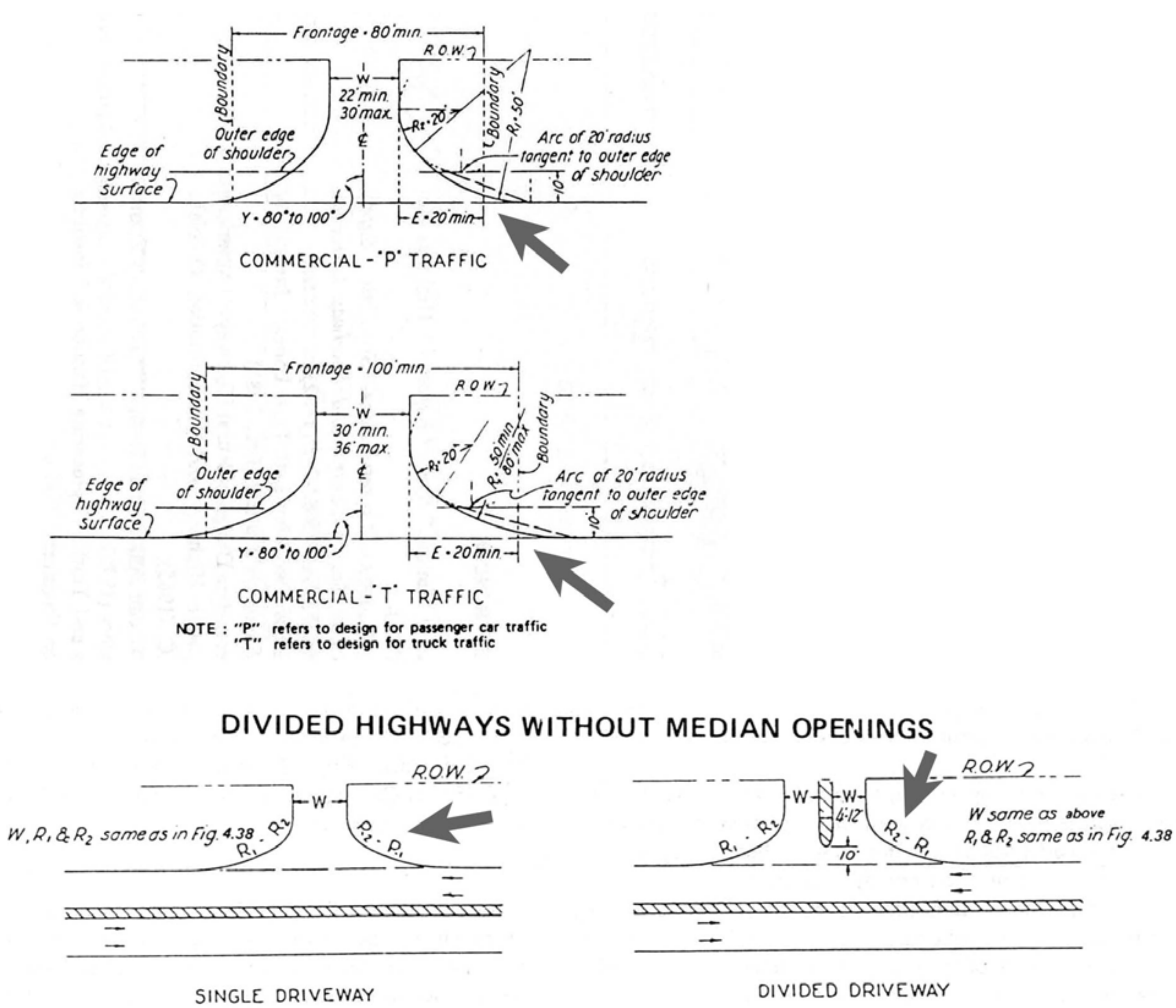
EXHIBIT 2-31 Recommended maximum change in driveway grade

NCHRP Intersection Guide

The *Intersection Channelization Design Guide*, while focused on roadway intersections, did contain material that is transferable to driveway intersections (*Neuman, 1985*). One short section specifically addressed driveway design. Among the features found in these driveway entry treatments were (see Exhibit 2-32):

- for commercial driveways, two different ranges (22-30 ft, 30-36 ft) of widths, depending upon whether designed for passenger car or for truck traffic; and
- compound radii for the driveway entry curves.

With respect to a vehicle on the roadway turning right into the driveway, it is not known why the radius of the initial compound curve in these drawings is greater than the radius of the trailing or second curve. Vehicle off tracking patterns are such that the tightest part of a 90^{O} turn is near the end of the turn.



Source: Neuman, NCHRP 279, pp.85-87

EXHIBIT 2-32 Driveway entry treatments

ITE Guidelines

Chapter 12 of the 1984 *Guidelines for Urban Major Street Design* by the Institute of Transportation Engineers (ITE) was devoted to driveways. Before applying guidelines, it recommended considering the following element (*ITE, 1984*).

- observing existing operation patterns, and analyzing accident patterns
- providing turning lanes on the street
- treating a high-volume two-way driveway as two adjacent one-way driveways
- basing the radius on the turning path of the design vehicle to prevent encroachment into travel lanes
- adequate storage distance from entrances to divergence points

The publication contained three separate tables for sight distances: one for passenger cars turning left to enter a driveway; one for semi-trailers turning left to enter a driveway; and one for semi-trailers exiting a driveway on to multilane roadways. It stated that driveways in high pedestrian-volume areas or commercial driveways should be oriented at an angle of not less than 70° from the roadway. The recommended practice also addressed spacing, median openings, grades, and relating driveway width to the radius.

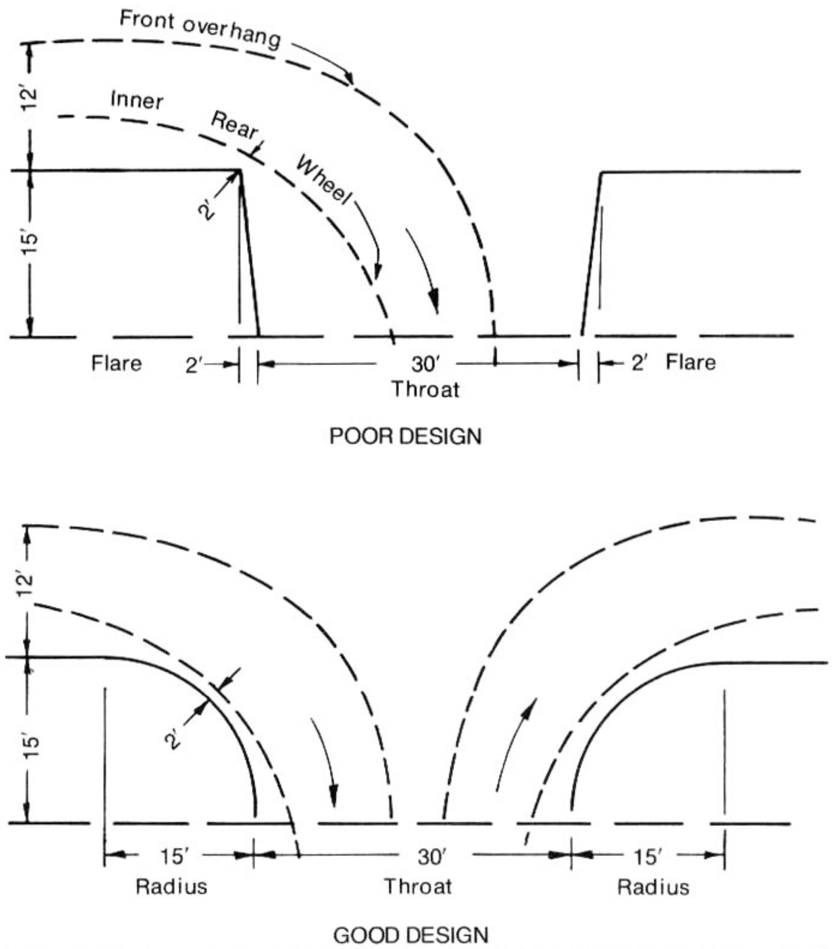
An ITE committee authored *Guidelines for Driveway Location and Design* (*ITE, 1987*). The publication enumerated 23 design considerations, and addressed design details such as radius and width, angle, spacing, and gradient. Among the differentiations included in the guide are the following:

Area: urban, rural;

Driveway land-use type: residential, commercial, industrial.

It recognized the wide variety of driveway situations, noting that it was unlikely that any single set of regulations could be applicable, even to single land-use type.

It recommended that the design for a particular driveway be influenced by considerations such as speed on the main roadway, volumes and characteristics of vehicles expected to use the driveway, and whether high pedestrian activity was expected. One emphasis was that vehicles turning into or out of driveways should not encroach upon adjacent lanes (see Exhibit 2-33). However, the guide noted that some issues were of less concern for low-volume driveways than for high-volume driveways. For instance, with reference to turning vehicles entering a driveway, it stated that for low-volume driveways, “it is acceptable for vehicles to sweep across the entire throat”.



1 ft = 0.3 m

Figure 4. *Swept path of passenger car turns to and from 12-foot curb lane for 2-way commercial or industrial driveways.* Source: *Guidelines for Driveway Location and Design*, Institute of Transportation Engineers, Washington, DC, p.9. ©1987. Used by permission.

EXHIBIT 2-33 Driveway radius, width, and vehicle turning path

The 1993 ITE recommended practice, *Guidelines for Residential Subdivision Street Design*, included the following observation (*ITE, 1993*).

> "Driveways are deceptively simple in appearance and often do not receive the design consideration that they merit. Common deficiencies include:
> a. Inadequate radii at intersection with street.
> b. Excessive grades and grade changes (breakover angles).
> c. Inadequate width.
> d. Inadequate sight distance because of bushes."

The publication recommended designing the typical residential driveway for only the passenger car. It recommended a minimum width of 10 ft, but also recognized the relationship between the driveway width, driveway entry radius, and the width of the street. It noted that with a 10 ft driveway and a 20 ft wide street, a 12 ft radius would be needed to avoid land encroachment; if the street width were 34 ft, the radius need be only 4 ft. It then went on to observe that on a local street, it was generally acceptable for a vehicle to temporarily be on the far side of the street when entering or leaving a driveway, so 5 ft was adequate for a typical driveway radius or flare. For driveways connecting two-car garages to the street, it recommended a minimum width of 18 ft, with 20 ft desirable. For driveways serving schools or apartments, widths up to 30 ft with a radius of 10 to 15 ft were recommended. Exhibit 2-34 shows the residential driveway detail design from this publication.

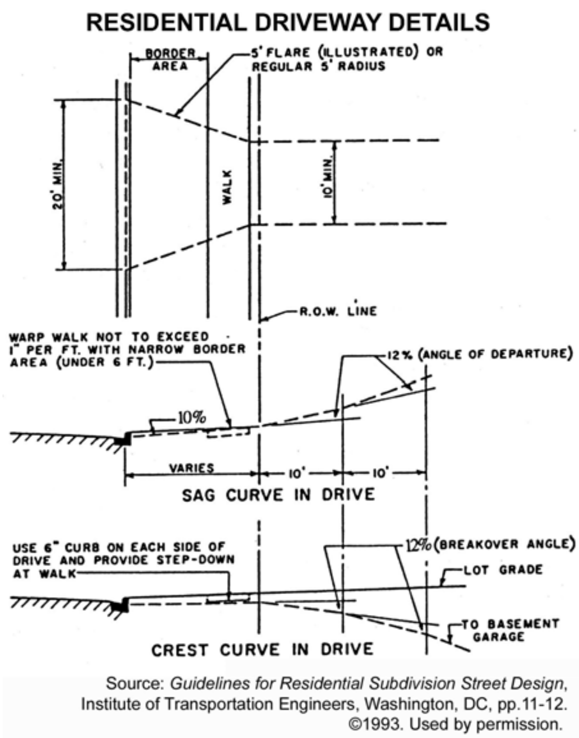


EXHIBIT 2-34 Residential driveway design detail

Guidelines for Triangular Islands

Some designers place a triangular island (sometimes known as a “pork chop”) in a driveway where it connects with the main road, to allow only right-in and/or right-out driveway movements. Triangular islands, especially smaller ones, are not fully effective: a certain fraction of drivers will drive around or over a small triangular island in order to make a desired left turn into or out of the driveway, or they may make use the right-turn exit lane to make a left turn into the site, driving the wrong way. A triangular island may be more effective if a larger turn radius is used.

A state DOT district engineer noted that in the vicinity of a triangular driveway island, they had installed pylons along the roadway centerline to further discourage wrong-way entry and egress. This installation to some degree replicated the effect of a restrictive median (*Gattis, 2005*).

Exhibit 2-35 shows a 1980's design from the standards of Lakewood, Colorado (*1982*). This island is intended to deter both left-turn egress and ingress.

A report prepared for the South Dakota DOT (*Dye, 2000*) recommended the alternative shown in Exhibit 2-36 as a means to more effectively discourage prohibited left-turn maneuvers in and out of a driveway.

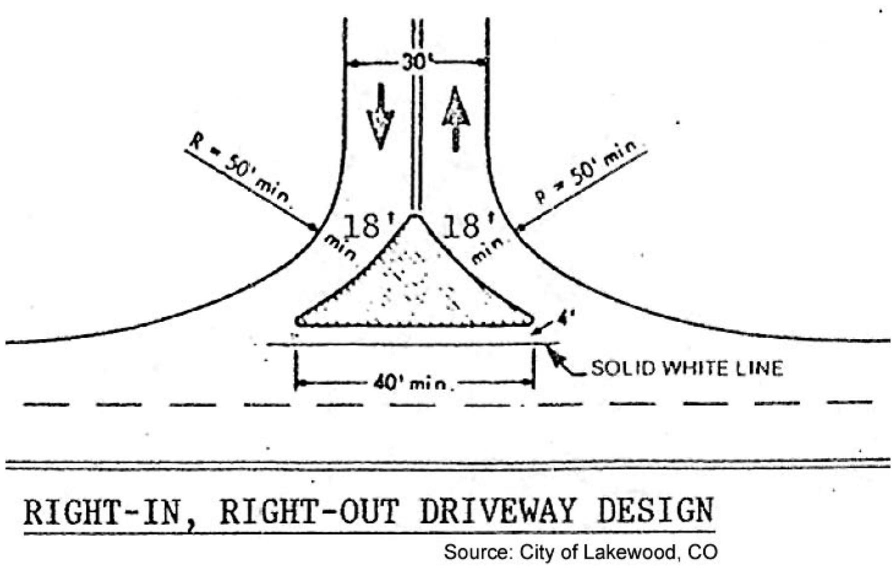


EXHIBIT 2-35 Island to restrict driveway turns

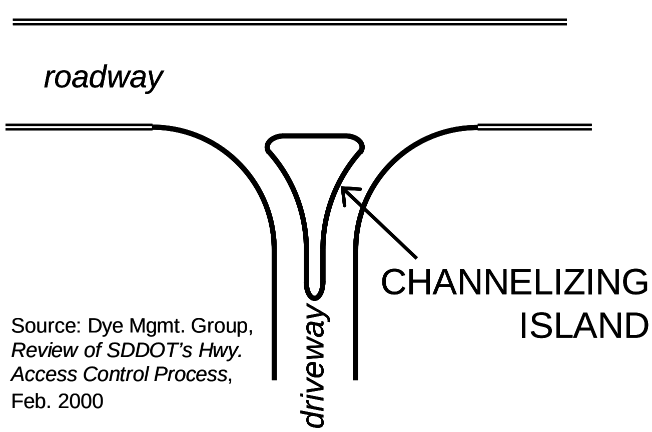


EXHIBIT 2-36 Driveway channelizing island treatment

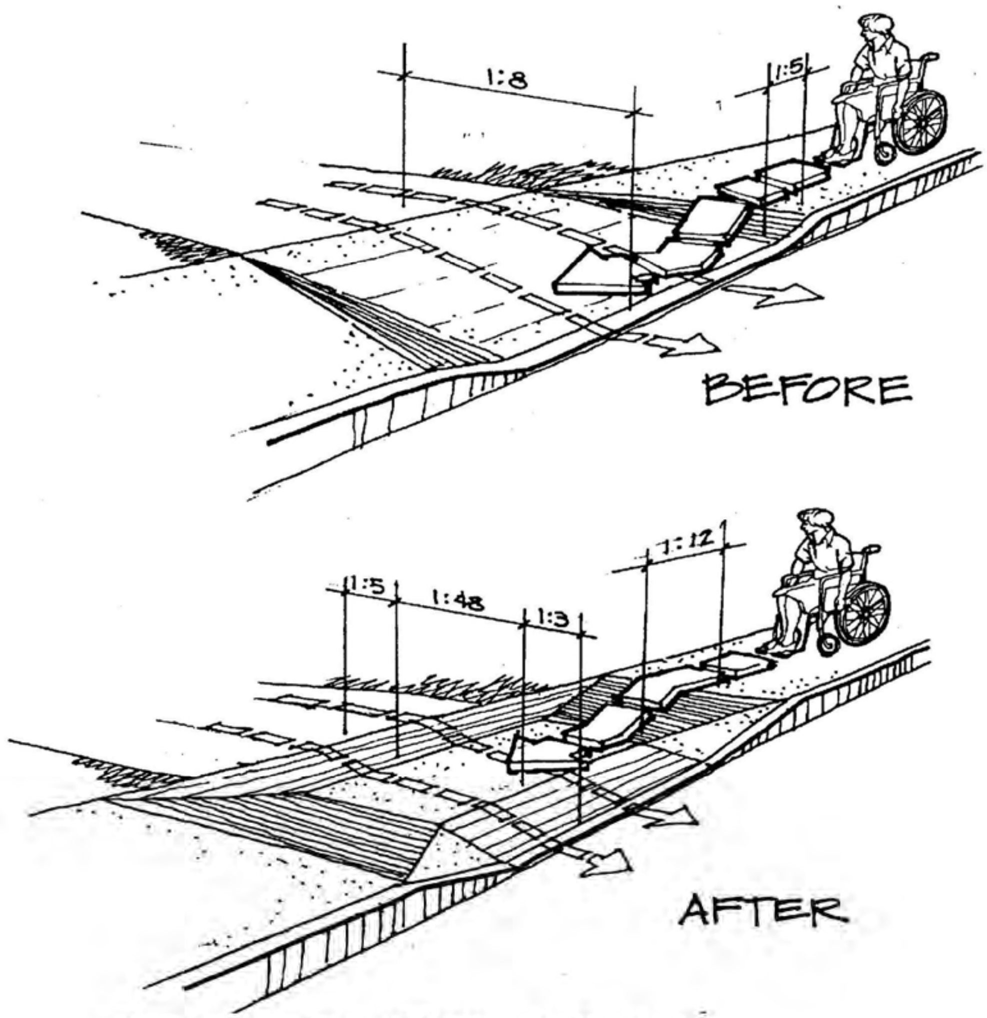
Guidelines for Pedestrians and ADA Compliance

While 2% cross slope on sidewalks has been a requirement of the Rehabilitation Act of 1973 in federally funded projects under the UFAS (Uniform Federal Accessibility Standards at http://www.access-board.gov/ufas/ufas-html/ufas.htm) since 1984, many jurisdictions are still building driveways crossings with much greater cross slope. Driveways such as those shown in the following 'before' graphic are common even in new construction. The 9th Circuit Court of Appeals ruled that Title II of the ADA applies to sidewalks (Barden v. City of Sacramento, http://www.dralegal.org/downloads/cases/barden/usca_opinion.pdf). Guidance documents provided by the Access Board illustrate driveway and sidewalk construction that minimizes cross slope on the sidewalk.

The *Draft Guidelines for Accessible Public Rights-of-Ways* (*Access Board, 2005*) was based on earlier recommendations of the 2001 Public Rights-of-Way Access Advisory Committee report, *Building a True Community* (*Access Board, 2001*). The draft guidelines would apply to all newly constructed or altered pedestrian facilities in public rights-of-way. In the draft guidelines, sidewalks are required to include a continuous pedestrian access route (PAR), which is required to meet the following specifications.

- A surface that is firm, stable and slip resistant.
- Minimum clear width of 4.0 ft (48 inches).
- Maximum cross slope of 2% (1:48).
- The grade does not exceed the grade of the adjacent roadway.
- No abrupt vertical changes of elevation in excess of 1/4". An elevation change between 1/4 and ½" must occur over a transition slope not to exceed 1V:2H.
- The gutter cross slope (or the counterslope at the base of a curb ramp) does not exceed 5% (1:20).

The draft guidelines do not include graphics illustrating sidewalk/driveway connections; however, graphics are available in other Access Board document illustrating sidewalk and driveway designs. The before-and-after pair in Exhibit 2-37 (*Access Board, 2001*) demonstrates how an existing sloping driveway that lacks a level sidewalk route can be retrofitted. Examining the drawings more closely, note that in the before situation, the person in the wheelchair is facing a 1V to 8H cross slope on the driveway. The compound slope at the interface between the driveway and sidewalk only exacerbates the situation. In the after drawing, the driveway has been modified to provide a level path (having a minimum width of 3 ft) across the driveway. On both sides of the driveway, the sidewalk ramps-down to this crossing at a maximum slope of 1 to 12. The short part of the driveway between the crossing path and the curb has a 1 to 3 slope, while the driveway behind the crossing path has a 1 to 5 slope.



Reconstruction of Driveway Aprons

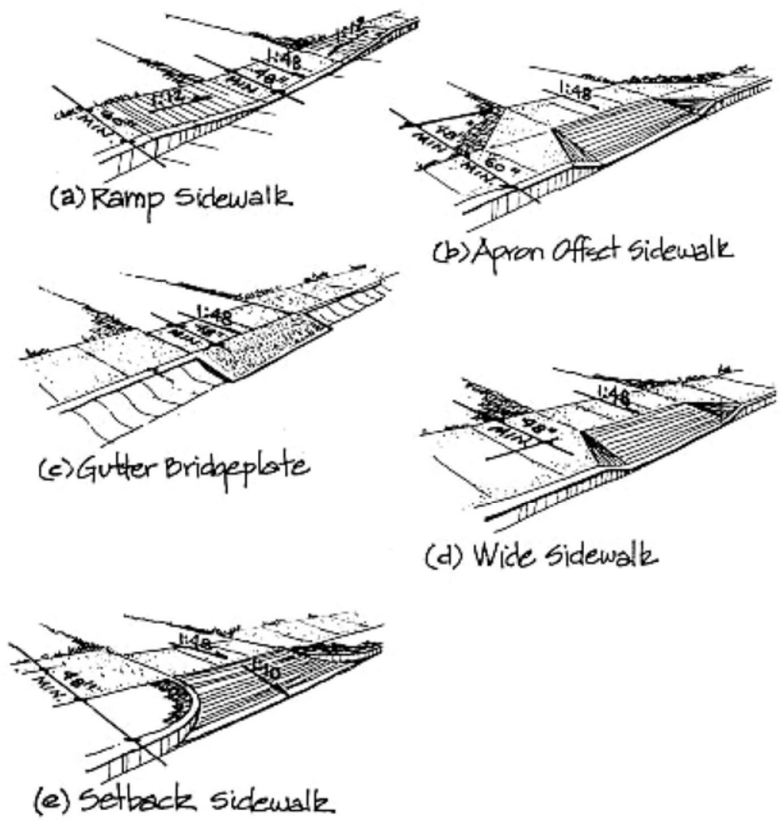
Isometric views of a public sidewalk and driveway showing before and after conditions. The before view shows a driveway crossing a public sidewalk and a typical steep cross slope condition. The after view shows transition ramps approaching a lowered driveway apron which allows a 48-inch wide PAR with 1:48 cross slope to complete the connection.

Source: PROWAAC, *Building a True Community*, Fig. X02.1B, p.38

EXHIBIT 2-37 Example before-and-after retrofit treatment for sidewalk-driveway crossing

Several example graphics were included in the PROWAAC report and in the *Accessible Rights of Way: A Design Guide* (*Access Board, 1999*), also published by the Access Board. Appendix E of the PROWAAC report contained a list of research needs. The issues of "cross slope and warp" appeared, and the difficulties encountered by those using mobility aids were specifically noted.

The following text and graphics (see Exhibit 2-38) were taken from *Building a True Community: Report of the Public Rights of Way Access Advisory Committee* (*Access Board, 2001*).



Sidewalk/Alley or Driveway Connections

Isometric views of five public sidewalk and driveway or alleyway connections. Illustrations show minimum PAR width of 48 inches (1220 mm) at the driving area and indicate maximum allowable cross slopes.

Source: PROWAAC, *Building a True Community*, Fig. X02.1A, p.37

EXHIBIT 2-38 Five means of treating sidewalk and driveway crossings

“X02.1.3 Clear Width….EXCEPTIONS:

1. **Driveways and alleyways**. Where public sidewalks intersect driveways or alleyways, the width of the pedestrian access route may be reduced to 48 inches (1220mm) across the driveway.

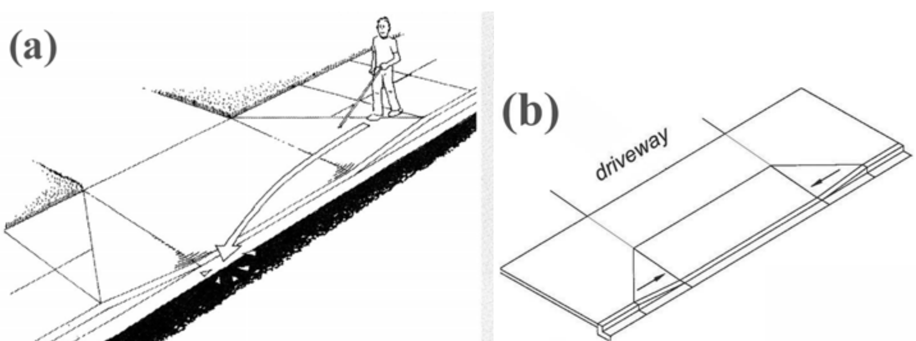
Advisory: *Excessive cross slope or change in cross slope on driveway aprons can be a significant barrier to public sidewalk use. Even with narrow public sidewalks along the curb, it is possible to design a public sidewalk to pass across the driveway apron without exceeding the 1:48 cross slope limitation. Existing non-complying aprons can be reconstructed to achieve a usable cross slope for a width of 48 inches. By breaking the* *driveway apron into three parts -- the apron on the roadway side, the sidewalk, and the apron on the property side -- vehicles must slow to negotiate the two steeper ramps on either side of the sidewalk crossing. When properly designed and constructed, these driveways will not cause vehicles to "bottom out."*

Note that in the AASHTO guide mentioned later in this section, four of these treatments (a, b, d, e) are shown, with slightly different names.

To assist impaired pedestrians with finding their way across an open expanse, *Building a True Community* (*Access Board, 2001*) recommends visually contrasting and tactile material at the edge of the pedestrian access route.

In 2001, the Federal Highway Administration published *Designing Sidewalks and Trails for Access*; Part 2 of 2, Best Practices Design Guide (*Kirschbaum et al., 2001*). One chapter addresses driveway crossings, and shows numerous examples.

An FHWA informational guide illustrated various accessible sidewalk design problems and solutions. One illustration (see Exhibit 2-39) displayed problems with one type of flared ramp design at a driveway (*Boodlal*). This sidewalk-driveway connection method shown in (a) on the left, with a single sloped plane extending all the way from the curb to the back of the sidewalk, should not be used. The cross slope of this design is more likely to exceed the 2% maximum allowed by the ADA. The slope that extends across the entire width of the sidewalk may direct visually impaired and other disabled users, such a person in a wheelchair, toward the street instead of along the intended pedestrian route. Drawing (b), on the right, shows a better method.



Source: *Accessible Sidewalks and Street Crossings* FHWA-SA-03-019, p. 17 Source: OTAK, *Pedestrian Facilities Guidebook*, Washington State DOT, Sept. 1997, p. 44

EXHIBIT 2-39 Problem with a full-width flared ramp design

AASHTO's 2004 guide for pedestrian facilities applied the term "buffer width" to the space between the sidewalk and the adjacent roadway (*AASHTO, July 2004*). For those sidewalks lacking a buffer (i.e., sidewalk is adjacent to the curb), the recommended minimum width was 6 ft in residential areas and 8 ft in commercial areas or along busy streets. This width provides space for snow cleared from the roadway, and places pedestrians farther away from splashing and from opening car doors. The publication recommended a minimum median or crossing island width of 6 ft to provide adequate space for a wheelchair, or more than one pedestrian.

The publication stated that there are four basic driveway design configurations that conform to accessibility requirements, described as follows:

sidewalk separated from roadway by adequate-width buffer;

wide sidewalk;

dipped sidewalk;

offset sidewalk.

The guide also noted that a drainage inlet grate located in a pedestrian's path is a potential problem. In such cases, it recommended that the opening width along the direction of travel should not exceed 1/2", and that elongated openings be oriented so the long dimension is perpendicular to the dominant direction of travel (*AASHTO, July 2004*).

Guidelines for Public Transit Stops

A study of factors associated with the location and design of bus stops (*Fitzpatrick, 1996*) distinguished between the "street-side" (area used by the transit vehicles) and the "curbside" (area used by transit riders as they approach or after leaving the transit vehicle). The report included a discussion of geometric design considerations for transit buses and riders. Optimum curb heights were said to be between 6" and 9". In locations where the sidewalk is adjacent to the curb, the bus patron waiting pad should be installed behind the sidewalk. If the sidewalk is recessed from the curb, then a paved path to the curb should be provided.

When possible, bus stops should not be located close to driveways. A number of considerations were offered for locations where a bus stop is close to the driveway.

- Do not block all of the driveways to a site.
- Locate the stop on the far side of the driveway, to improve the visibility available to motorists exiting the driveway (see Exhibit 2-40).
- Locate a bus stop so that transit patrons board from or step onto a curb and sidewalk, not the driveway surface.

Other Guidelines

The following list highlights some of the other noteworthy content from the reviewed documents.

- Williams surveyed the driveway regulation and permit practices of the 50 states, and documented them in NCHRP Synthesis 304 (*Williams, 2002*).

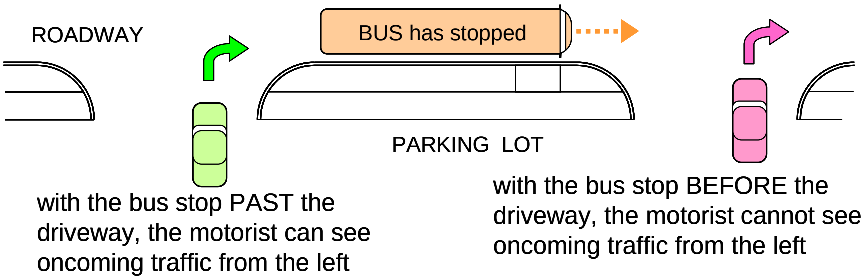


EXHIBIT 2-40 Bus stop location with respect to driveway

- Richards gathered information from 34 Texas cities, and found a "great inconsistency in urban driveway regulations," giving an example that the maximum driveway curb return radius varied from 5 ft to 50 ft. Over 1/3 lacked commercial driveway criteria for maximum allowable radius and for minimum width (*Richards, 1980*).
- Carter and Homburger (*1978*) stratified driveway designs by type of driveway and type of environment (including the amount of pedestrian activity).
- As an alternative method of serving up to six residential lots, one publication advanced the concept of the shared driveway (*LaHue, 1990*). It is described as being privately owned and maintained; paved to driveway standards, not street standards; branching off to the lots served; and not requiring a turnaround area at the terminus.
- The city of San Buenaventura, CA (*undated*) set a 12 ft minimum width for a single-family residential driveway, and set the maximum width according to the capacity of the garage: maximum for single garage, 16 ft; double garage, 20 ft; triple garage, 24 ft.
- The *Fundamentals of Traffic Engineering* text (*Homburger et al., 1996*) recommended the driveway dimensions listed in Exhibit 2-41.
- A past city of Chicago, IL standard had the following definition for "driveway" (*Bureau, 1984*)

> "A driveway is a paved roadway constructed **within the public way**, connecting the public roadway with private property. Its purpose is to provide access for motor vehicles to the private property, and is to be used in such a way that the access into the private property will be complete, and will not cause the blocking of any sidewalk, parkway, or street roadway. [the bold emphasis has been added]

The standard specifically mandated that driveway traffic will not block a sidewalk or street. Also note that this definition reflected the roadway engineers' use of the word "driveway," focused on that part of the driveway that is within the public way. This is in contrast to how the word "driveway" is generally used, denoting a way between the public roadway and a private building or parking lot, not just that part of the driveway in close proximity to the roadway. The standard went on to relate multifamily residential driveway width to the number of dwelling units, and commercial driveway with to the expected vehicle type (see Exhibit 2-42).

EXHIBIT 2-41 Recommended basic driveway dimension guidelines

	Residential	Commercial	Industrial
Width (m)			
One-way driveways	3.0	4.6	6.1
Two-way driveways	3.0-7.3	9.1-11.0[a]	12.2-15.2
Minimum curb return radius[b] (m)	1.5	4.6	6.1
Minimum spacing[c] (m)			
street corner to driveway	1.5	3.0	3.0
between adjacent driveways	0.9	0.9	3.0
Minimum angle	45°	45°	30°

Source: *Fund. Of Traffic Engineering*, 14th ed., p.19-5

a: A 11.0-m driveway is usually marked with 2 exit lanes and 1 entry lane.
b: For major traffic generators radii should be much higher.
c: Dimension for tangent between adjacent curb returns.

EXHIBIT 2-42 Chicago driveway dimension requirements

	Minimum width (in feet)	Maximum width (in feet)
Residential Driveways		
(4 or less apartments)	8	16
(more than 4 apartments)	8	24
Commercial Driveways		
where the driveway accommodates passenger cars only	--	24
where the driveway accommodates commercial vehicles	--	30

Source: City of Chicago, IL, 1984

- In a discussion of bicycle facility issues, it was noted that landscaping, vegetation, and fences tend to interfere with sight distance and visibility at driveways. The "poor visual relationships" that arise when motor vehicles back out of or turn in to driveways make matters worse (*Smith, 1976*).
- NCHRP Report 348 (*Koepke and Levinson, 1992*) and Levinson (*1984*) gave detailed examples of left-turn controls to minimize driveway conflicts with streets and -site roads.

- Lakewood, Colorado's (1982) design standards included a two-page table that specified various amounts of on-site stacking (storage) distances according to the types of land-use. They also included (*Lakewood, 1985*) vertical profile design controls (see Exhibit 2-43).

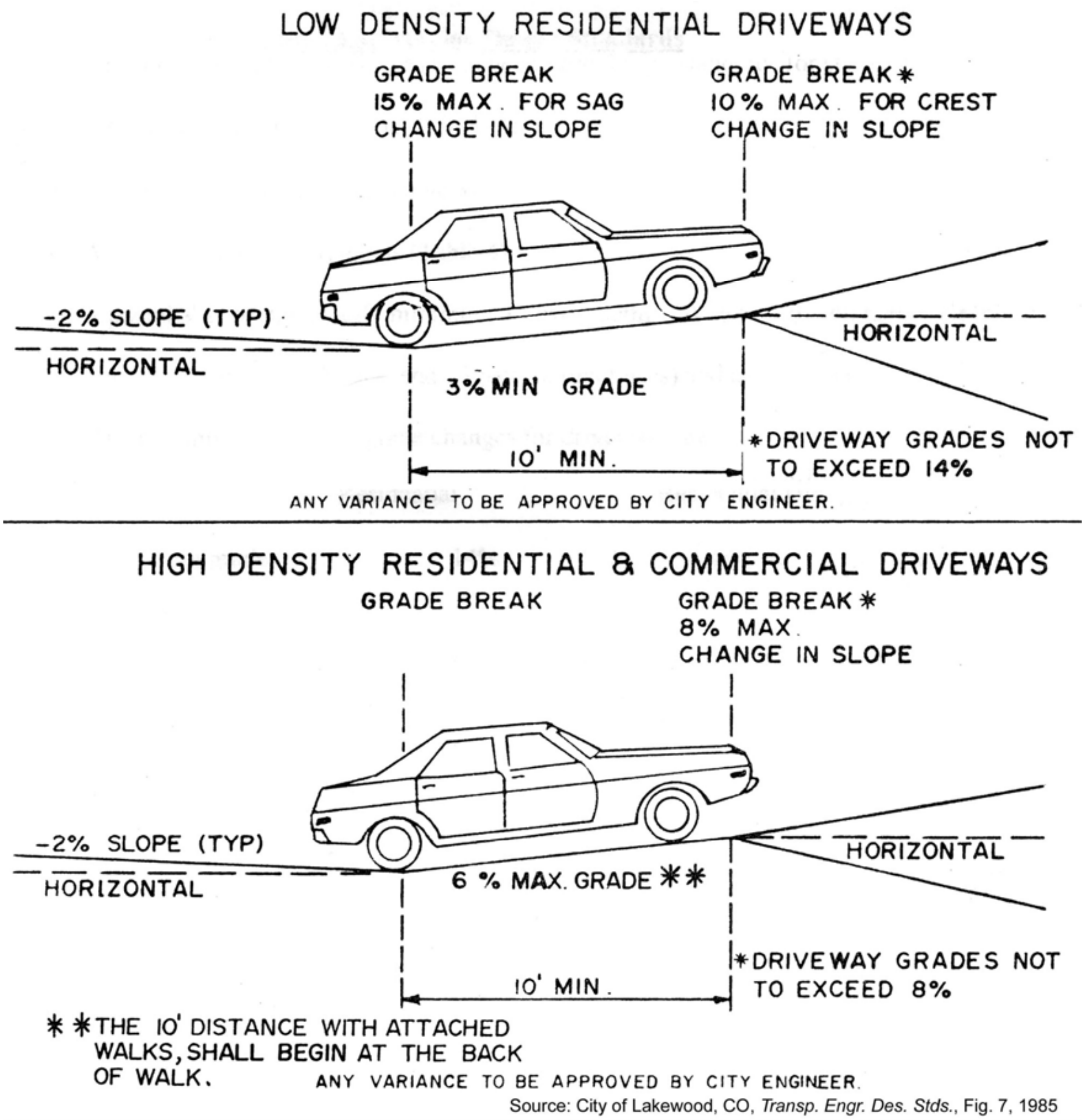


EXHIBIT 2-43 Example vertical profile regulations

- Stover and Koepke (*2000*) advised that when connecting a driveway to an existing street, the entire curb and gutter be removed and the gutter constructed as an integral part of the driveway apron. They were opposed to constructing a driveway with a "lip at the face of the curb line extension through the driveway." Stating that an automobile could not negotiate a grade change in excess of

14% between the roadway cross slope and the apron slope, they recommended the vertical alignment design guidelines in Exhibit 2-44.

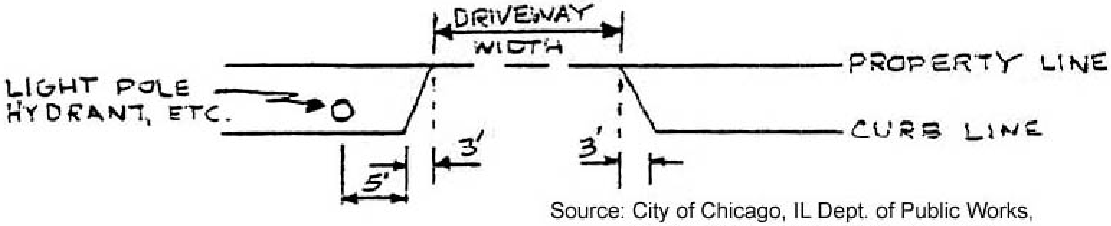
EXHIBIT 2-44 Maximum change in grade between the roadway cross slope and the apron slope

Roadway class	Maximum change in grade
Major arterial	5%
Minor arterial	6%
Major collector	
nonresidential	8%
residential	10%
Minor collector	10%
Local street	12%

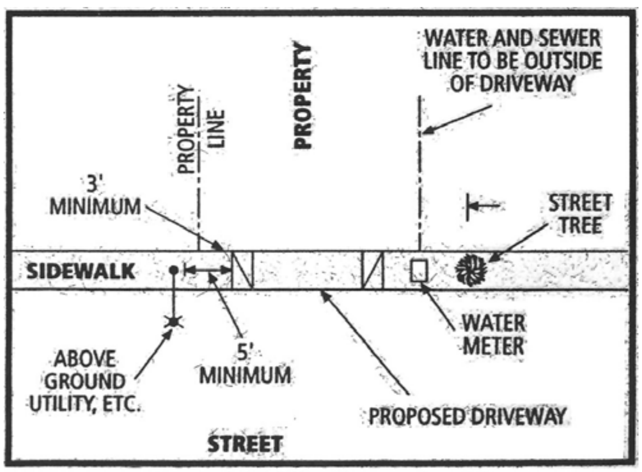
Source: Stover and Koepke, "An Intro. to Acc. Mgmt."

- Stover and Koepke (*2002*) published a greatly-expanded second edition of their *Transportation and Land Development* book. A chapter devoted to driveway design addressed the design of driveway throat length (also known as "driveway connection depth"), the distance measured along the driveway from the roadway edge to the first point at which there is any traffic movement that conflicts with the driveway.
- Some jurisdictions specify lateral clearances between the driveway edge and fixed objects. Simi Valley requires a 5 ft clearance between trees and driveway edges, Seattle requires 7.5 ft, and Montgomery recommends 15 ft (*Dixon, 2008*). Specifications for driveway clearances from roadside utility fixtures from Chicago, IL (*Bureau, 1984*) and San Buenaventura, CA (*undated*) are presented in Exhibit 2-45.
- The American Planning Association recently published the first edition of *Planning and Urban Design Standards* (*APA, 2006*), which covers a very broad range of topics. One page shows alley driveway designs.
- In a review of traffic considerations associated with schools, a survey of agencies produced the following material (*Cooner et al., 2004*). Exhibit 2-46 lists recommended practices for school driveway location, and Exhibit 2-47 shows driveway connection transition design treatments. The treatment in the upper part of the exhibit, presumably for general traffic to and from the school site, shows one entry and two exit lanes. The lower drawing, showing a school bus driveway, calls for a larger radius (40 ft) to accommodate turning buses. Both driveways have a flared, extra-wide (18 ft) throat opening for inbound traffic.

Driveways should be constructed with three-foot flares on each side. These flares must clear all utilities by a minimum of five feet (as illustrated below), or relocation will be required at the applicant's expense.



Source: City of Chicago, IL Dept. of Public Works, *Design Stds. Manual,* p.21, Jan. 1984



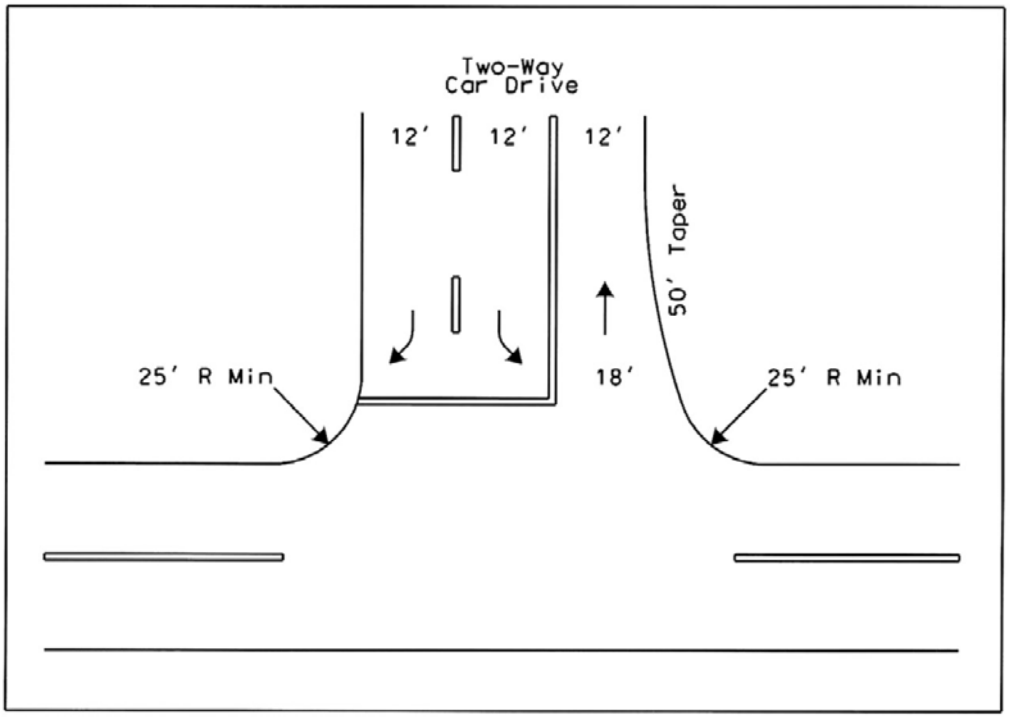
Source: City of San Buenaventura, CA

EXHIBIT 2-45 Examples of edge clearance from utility

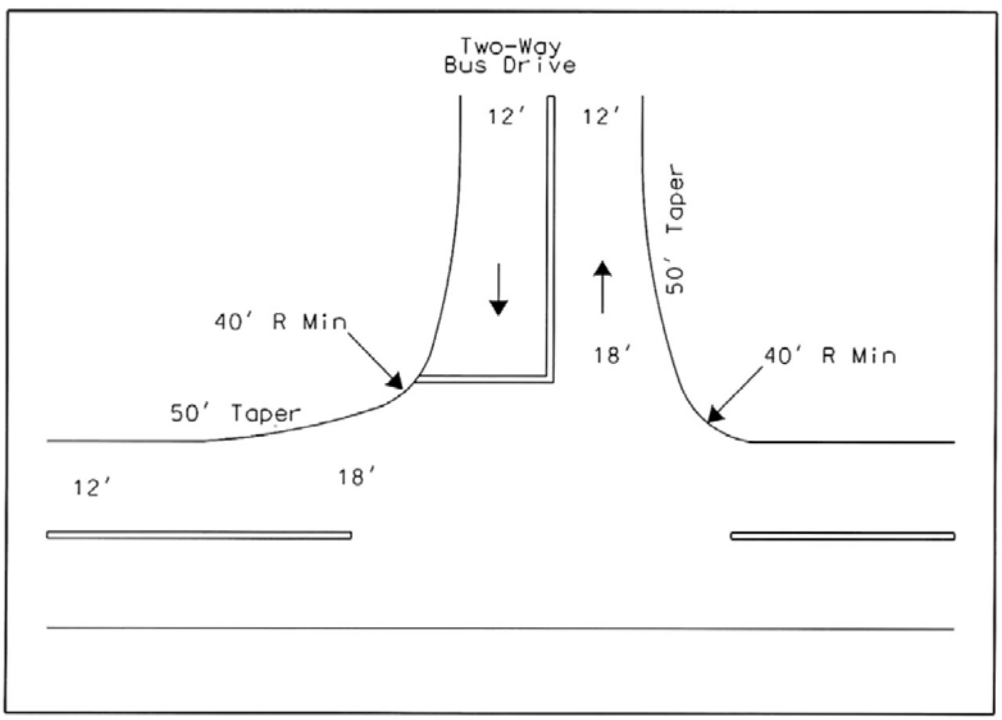
EXHIBIT 2-46 Guidelines for locating school driveways

Guidelines for the Relative Placement of Driveways	Source
Locate the bus area so that buses exit upstream of automobiles and gain priority, thereby reducing delay.	Douglas County–Colorado (*19*)
The one-way driveway into the school should be located at the far left side from the direction where the majority of traffic is coming from such as a city. In addition, the through roadway serving the one-way into the school should have a left- and right-turn lane. In this situation, the left-turn traffic only has to yield to the opposing through traffic lane and the right-turn lane. The majority of those exiting the school area will be turning right, creating only one vehicle conflict.	Minnesota DOT (*26*)
Driveways should not be located too close to nearby intersections. Doing so will create offset or dogleg intersections with other streets or high-volume driveways. Offset intersections can create erratic patterns and detract from drivers' abilities to look out for pedestrians.	School Bus Fleet (*36*)

Source: Cooner et al., *Operations and Safety Around Schools ...*, TTI 4286-3, Tab. 46, p.5-42



South Carolina DOT Layout and Design for Two-Way Car Driveway (*7*).



South Carolina DOT Layout and Design for Two-Way Bus Driveway (*7*).

Source: Cooner et al., *Operations and Safety Around Schools ...* , TTI 4286-3, Fig. 48, 49, p.5-43

EXHIBIT 2-47 School driveway entry treatments

Literature Review Conclusion

Two general groups of documents were reviewed, research reports and guidelines. Some of the content specifically addressed the geometric design of driveways, while other material addressed related issues or issues with an application to driveway design. The sources reviewed addressed needs of a range of users, not just motorists.

The literature review summarized the findings of research related to pedestrian and bicyclist characteristics that may be relevant in the design of driveways. Since the paths of both bicyclists and pedestrians often cross driveways, attributes and concerns of these user groups were reported. The issue of making drainage grates safe for bicyclists has been established for decades. Characteristics of pedestrians can make them vulnerable when crossing a driveway. Key pedestrian-related elements addressed in the research that affect driveway design include walking speeds and gap acceptance. In addition, research has been done on the effects of cross slope on disabled pedestrians.

The review also summarized research topics related to designing driveways to accommodate the capabilities and limitations of drivers and motor vehicles. Previous studies have addressed topics related to access management or have examined the effects of driveway characteristics on the flow of motor vehicle traffic. Different studies conducted over many decades have found that managing the number and location of access connections can improve the safety of a roadway. Directly related to the geometric design of driveways is research on the effects of driveway horizontal and vertical alignment on motor vehicle operation. This includes research on driveway entry and turning vehicle dimensions and driveway pavement markings and channelization. Safety research summarized in this document addressed bicycle, pedestrian, and driveway collisions, as well motorist yielding behavior (to pedestrians). In addition, errors in crash data that may skew numbers of driveway-related collisions were discussed.

The guidelines that were identified and summarized came from organizations that have developed relevant guidance that could be applied to driveway design. These organizations include the Access Board, American Association of State Highway and Transportation Officials, Federal Highway Administration, Institute of Transportation Engineers, and a range of others. These guidelines addressed a variety of elements, such as triangular islands, compliance with ADA requirements, public transit, and edge clearance.

2.3 ADDITIONAL SOURCES

To expand the scope and breadth of information incorporated into this project during the initial stages, additional sources were queried. Project researchers requested input from stakeholder groups, searched for sources of motor vehicle ground clearance measurements, and gathered summary information from readily-available crash data.

Contacts with Stakeholder Groups and Organizations

As the work on the initial tasks of this project proceeded, it became evident that it would be desirable to make contacts with organizations and groups that represent stakeholders (e.g., bicyclists, pedestrians, disabled pedestrians, public transit users) who may be affected by driveway designs and driveway traffic. The message to these organizations and groups began with a brief explanation of the research project, then continued with a request for the following types of input.

1. submit any data, research findings, or other information that you think should be considered when driveway geometrics (elements such as the various physical dimensions, grade/slope, shape at the entry, use of islands, drainage) are designed
2. suggest measures that could be used to evaluate the performance of driveway designs or design elements, as related to safe and efficient travel by the various user groups
3. suggest aspects or issues related to driveway geometric design that need additional research, and the method(s) to study the issue(s)

This message was sent (usually via e-mail) to 14 groups and organizations that the research team identified. The contacts generated 13 separate responses. Some of respondents were state DOT employees.

The content of these responses ranged from opinions about design nuances to proposed research activities. Some of the main issues from the comments are highlighted below.

1. Driveway opening width can be incorporated into a curbside transit-bus stop.
2. Drainage effects need to be considered when designing the vertical profile.
3. There is a need for more emphasis on who has the right-of-way at sidewalk/driveway crossings.
4. Suggested research topics.
    a. effectiveness of special pavement markings to indicate the presence of a bicycle path
    b. effectiveness of treatments to improve detection of the walking path for pedestrians with impaired sight
    c. effects of driveway-related speed differential (on the main roadway) on crash rates
    d. coordinating driveway geometry and roadside mailbox locations

Condensed and reformatted excerpts from each response are in Appendix C.

Contacts with Sources of Automobile Ground Clearance Dimensions

A comprehensive database of pertinent vehicle dimensions would need to be available before attempting to examine and define limiting driveway profile attributes. A number of publications list the overall and the wheelbase lengths of motor vehicles. The challenge lies in finding front overhang, rear overhang, and ground clearance dimensions for the wide array of motor vehicles currently on the nation's roadways.

Through 1994, the American Automobile Manufacturers Association (AAMA) published "Vehicle Dimensions". The publication of this small document was discontinued, and AAMA no longer exists.

Numerous leads were pursued in an attempt to identify a source for the specific vehicle dimensions that would be needed to determine the limits of acceptable change in driveway vertical profile. The research team performed an online search, and approached automobile manufacturers and automotive publications. After numerous attempts to find either a source of acquiring this information or an actual source, the only fruitful response was from Daimler-Chrysler, who had posted that information online for their current models.

Appendix D describes this effort and the findings in more detail.

Examination of Crash Data

To have a preliminary, broad understanding of the magnitude of the damage and injury associated with the current state of practice, readily available crash data were reviewed and summarized. These include summary statewide driveway and non-motorized collision totals from Arkansas in 2005; pedestrian collision totals from Morgantown, WV, in 2002, 2003 and 2004; and both driveway and non-motorized totals from Springdale, AR in 2006. This information is in Appendix E.

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CHAPTER 3
Identify Driveway Research Needs

This research project was structured so that information about a wide range of driveway design issues was first collected, and from that the project oversight panel would then identify the issues on which research was to be conducted. This chapter summarizes the effort to identify and define candidate issues for research.

3.1 IDENTIFY ELEMENTS AND DEVELOP PERFORMANCE MEASURES

The various components of the elements of driveway geometric design individually and collectively influence vehicle and pedestrian movements and performance. Task 2 of the project involved developing a list of driveway-related geometric elements and identifying how the performance of each could be described or evaluated. The draft report prepared for the project oversight panel:

1. contained an extensive list of factors that influence how well a driveway functions in operation;
2. identified principal driveway design elements; and
3. listed indicators that measure the performance of one or more components of the principal driveway design elements.

The components of design are related to the users (e.g., drivers, pedestrians), the vehicles, the roadway and associated facilities, and the environment in which they occur. Many factors, while present and recognized by the designer, are outside the control of the designer. Specifically, the driveway designer typically has little control over user, vehicle, or surrounding environment factors. In addition, the design of a driveway and the selection of a specific method from among a number of alternatives proceed within the context of already-determined conditions and constraints. Previous decisions can cause many elements to be literally be fixed in concrete (or asphalt), and experience has taught practitioners the desirability of having the proper land use planning and development standards in effect, to block the construction of designs that will create problem situations in the future.

The following exhibits list almost 100 factors that may affect the operation of a driveway. The individual factors were grouped into related categories. Exhibit 3-1 lists factors over which designers often have little or no control. Exhibit 3-2 lists those factors over which designers typically have some degree of control and can select from among different design options. Some of these factors are considerations only for higher volume or more challenging driveway design situations. For residential, farm, and other lower-traffic volume land uses, many of these factors will seldom if ever come into play.

EXHIBIT 3-1 Factors often beyond the control of the driveway designer

	Shared Elements, Surroundings	
1	Land use	
2	User and vehicle mix and composition	
3	Temporal variation: season, day of week, time of day	
4	Weather and weather effects	
	Sidewalk-Driveway Intersection	
5	Sidewalk placement	(adjacent to or offset from the curb or edge)
	Roadway-Driveway Intersection	
6	Elevation difference between roadway surface and abutting property	
	Roadway in vicinity of the Driveway	
7	Width of roadway	
8	Lanes	(number, width)
9	Lane type	(travel, HOV, bicycle, turn, parking)
10	Cross slope	(travel lanes, shoulders)
11	Horizontal alignment of roadway	
12	Vertical profile of roadway	
13	Sight distance restrictions	
	User characteristics - Bicyclist	
14	Bicyclist perception-reaction process, time	
15	Speed	
16	Braking capability	
17	Sight distance need	
	User characteristics - Pedestrian	
18	Pedestrian perception-reaction process, time	
19	Speed	
20	Sight distance need	
	Special needs groups	
21	General - children, elderly	
22	Disabled (e.g., mobility, visually)	
23	Legal mandates - disabled	
	User characteristics - Vehicle, Driver	
24	Driver perception-reaction process, time	
25	Speed	
26	Deceleration characteristics (typical)	
27	Braking capability (limiting)	
28	Sight distance need	
29	Vehicle width	
30	Vehicle length	
31	Vehicle turning radius	
32	Vehicle front overhang, wheelbase, rear overhang, and ground clearance dimensions	

EXHIBIT 3-2 Factors often within the control of the driveway designer

	Shared Elements, Surroundings	
1	Illumination	
2	Conspicuity	(to visually detect an element at a distance)
3	Sight obstructions	
	Driveway	
4	Width	(maximum and minimum; sufficient for ped. refuge)
5	Lanes	(number, width)
6	Median in driveway:	(absence or presence)
7	width	
8	type	(raised, flush, depressed)
9	nose-end recessed from edge of through-road	
10	Cross slope, cross slope transition runoff	
11	Horizontal alignment, curvature	
12	Connection depth (throat length)	
13	Traffic controls or other potential impediments to inbound traffic (inc'l entry gate)	
14	Paving length	(applicable where have unpaved driveway)
15	On-site turn-around capability	(where backing into roadway is undesirable)
16	Driveway edge	(edge drop off, barrier)
17	Space for nonmotorized users	(e.g., pedestrian movement parallel to driveway)
18	Driveway border treatments	(sideclearance, sideslope)
	Vertical profile	
19	grade	(maximum and minimum)
20	change of grade (grade breaks)	
21	vertical curve design criteria	
22	Vertical clearance	(from overhead structures, utility lines)
23	Drainage (separate from intersection drainage)	
24	Other special situations	(e.g. railroad crossing, trail, bridle path, etc.)
	Sidewalk-Driveway Intersection	
25	Sidewalk cross slope (i.e., driveway grade)	
26	Path definition	(e.g., visual, tactile cues)
27	Crossing length (i.e., driveway width)	
28	Angle of intersection with driveway: flat-angle (turn angle < 90^{O}); right-angle (turn angle ≈ 90^{O}); sharp-angle (turn angle > 90^{O})	
29	Bearing of sidewalk relative to street:sidewalk diverging from, parallel to, or converging with the street	
30	Grade of sidewalk (i.e., driveway cross slope)	
31	Vertical profile of pedestrian route	(abrupt elevation change: max. 1/4")
32	Sidewalk-driveway interface treatment:detectable warnings for visually impaired (e.g., truncated dome) (only at certain locations, inc'l. at signalized crossing; refer to guidelines)	
	Roadway-Driveway Intersection	
33	Angle of intersection with street: flat-angle (turn angle < 90^{O}); right-angle (turn angle ≈ 90^{O}); sharp-angle (turn angle > 90^{O})	
34	Cross slope of street and shoulder, considered with driveway grade	
35	Curb threshold treatment	(rolled, vertical lip, counterslope, continuous)
36	Curb-termination treatment	(abrupt end, drop-down, returned)
37	Entry transition shape	(e.g. radius, flare/taper, straight, etc.)
38	Entry transition-shape dimensions	(radius, flare dimensions)
39	Channelization of right turn from street into driveway	
40	Channelization of right turn from driveway into street	
41	Channelization in the driveway: triangular island to prohibit in and out left-turns	
42	Channelization in street - street median prohibits all left-turns in/out of driveway	
43	Channelization in street - street median prohibits one but not both left-turns	
44	Drainage: confining the gutter flow	
45	Drainage: inlet type and location	
46	Clearance from fixed objects, appurtenances	
47	Pavement surface deformity	(corrugation, potholes)

EXHIBIT 3-2, con't.

Traffic Controls (for driveway vehicles)

48	Driveway-roadway intersection control	(none, yield, stop, signal)
49	Turn restrictions	
50	One-way operation	(one-way, do not enter)
51	Markings	(pavement, delineators)
52	Other	

Roadway in vicinity of the Driveway

53	Right-turn lane attributes:	(absence or presence)
54	right-turn lane width	
55	right-turn lane deceleration, storage length	
56	right-turn lane entry transition shape	
57	right-turn lane offset	
58	Left-turn lane attributes:	(absence or presence)
59	left-turn lane width	
60	left-turn lane deceleration, storage length	
61	left-turn lane entry transition shape	
62	left-turn lane offset	
63	Number of driveways per site	
64	Driveway spacing from upstream access connection	
65	Driveway spacing from downstream access connection	

Elements that represented the most significant combinations of factors, and seemed to have the potential to significantly affect driveway operations and safety for the various user groups, were arranged for presentation. These elements include:

1. Cost and constructability
2. Visual and tactile cues (to identify the sidewalk path and driveway) and pedestrian route accessibility
3. Driveway width (as perceived by bicyclists and pedestrians)
4. Driveway connection transition plan-geometry effects on turning vehicles (related to driveway width, as perceived by motorists)
5. Driveway throat design
6. Driveway border design
7. Channelization
8. Sidewalk cross slope (driveway grade)
9. Driveway grade (sidewalk cross slope) and vertical alignment
10. Roadway-driveway threshold treatment
11. Driveway visibility
12. Auxiliary lanes for right-turn entry movements into driveways
13. Drainage of surfaces occupied by user groups
14. Spacing between driveways

This section presents the selected design elements and associated design objectives. For each element, there is also a list of possible performance measures that are related to the design objectives. Exhibit 3-3 displays these elements in context.

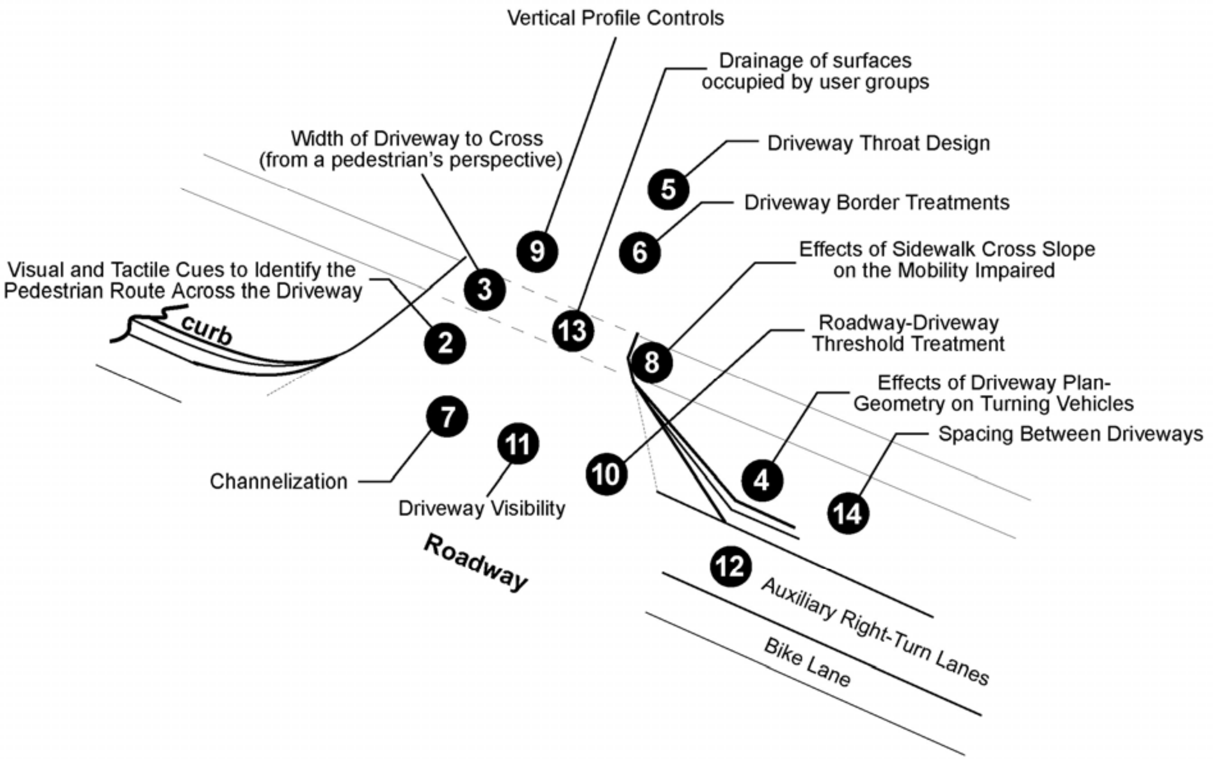


EXHIBIT 3-3 Driveway design elements depicted

Some objectives or performance measures could be associated with multiple design elements. In actual design practice, an objective listed herein under one element may be met by the design of another element. For instance, a median included as a part of the driveway throat design may also improve the conspicuity (i.e., visibility) of the driveway for an approaching driver. When creating a list of design objectives and performance measures, a good degree of judgment was exercised to balance completeness on one hand and reducing redundancy on the other.

In some cases, the objectives of the different driveway users (bicyclists, drivers, pedestrians) may come into conflict. In that event, the designer is forced to set priorities or make compromises among the objectives.

In theory, crash history would offer insight into the performance of many design elements. In actuality, the insight that could be gained from examining the recorded crash history may be subject to limitations. As stated in the discussion of driveway grade, later in this report, for some purposes the crash data base may be inadequate or misleading. This is due to the presently inherent limitations in crash databases. Some types of causal factors and locations may escape the notice of accident investigators or data entry personnel.

Because of the complexity of the issues, it was deemed simpler to address driveway width in two separate discussions, one of width from the perspective of a bicyclist or pedestrian, and the other of width in conjunction with other driveway entry plan-view elements, such as the radius.

Driveway Cost and Constructability

Two of the objectives of driveway design are to minimize cost and to simplify construction. However, unless two or more alternate designs are found to be functionally equivalent (offer comparable levels of utility and safety for the users), comparing the costs without being able to quantify the difference in benefits is subject to valid criticism. Ideally, such information would be obtained from various geographical regions of the country. Since the relative benefits of a number of alternate design treatments are unknown, this topic was not pursued.

Visual and Tactile Cues and Pedestrian Route Accessibility

In this context, visual and tactile cues are desired in order to help people who are blind or have low vision to identify and negotiate the driveway location, and the sidewalk path across the driveway. Concerns have been expressed by a consumer group of pedestrians with low vision about maintaining their line of travel across the driveway. Having an accessible pedestrian route helps people with disabilities negotiate the sidewalk path across the driveway.

* Design objectives include:

1. recognize that a driveway has been encountered
2. identify the intended path, in order to minimize deviations from the intended pedestrian path
3. provide an accessible pedestrian route with adequate width
4. avoid abrupt elevation changes along the accessible pedestrian route

* Performance measures for how well the objectives are satisfied can be classified in the following categories, along with the related measures:

for all disabled pedestrians --

- no lip or abrupt elevation change exceeding 1/4" on the accessible pedestrian route
- cross slope not exceeding 2%

in addition, for blind or low-vision pedestrians --

- ability to recognize the sidewalk location
- ability to recognize the driveway location
- the amount of deflection from the intended path (if the path is parallel to the roadway, toward or away the roadway) while crossing
- perception of safety and comfort while crossing

PROWAAC and Draft PROWAG do not recommend using detectable warnings at driveways. Specifications are provided for size, location, dome spacing and size, alignment, and visual contrast. The PROWAAC commentary contains the following recommendations regarding the appropriate locations for use of detectable warnings within the public rights-of-way.

> “Detectable warnings shall be provided only:
> 1) where a pedestrian way crosses a vehicular way, but not at unsignalized driveways;
> 2) where a rail system crosses a pedestrian way;
> 3) at reflecting pools in the public right-of-way;
> 4) at cuts through islands and medians; and
> 5) where required by ADAAG Chapter 10.”

In the Draft PROWAG, the Access Board provides an advisory note that specifically addresses detectable warnings at driveways.

> Detectable warning surfaces shall comply with R304.
> Advisory R221 Detectable Warning Surfaces. Detectable warning surfaces are required where curb ramps, blended transitions, or landings provide a flush pedestrian connection to the street. Sidewalk crossings of residential driveways should not generally be provided with detectable warnings, since the pedestrian right-of-way continues across most driveway aprons and overuse of detectable warning surfaces should be avoided in the interests of message clarity. However, where commercial driveways are provided with traffic control devices or otherwise are permitted to operate like public streets, detectable warnings should be provided at the junction between the pedestrian route and the street.

Other sections herein list additional accessible-route design objectives and performance measures.

Driveway Width

This element is viewed from the perspective of a bicyclist or pedestrian crossing a driveway.

* Design objectives for driveway width include:

1. minimize bicyclist and pedestrian crossing distances and times
2. minimize conflicts with motor vehicles

* Performance measures for how well the objectives are satisfied can be classified in the following categories, along with the related measures:

for blind, visually impaired, mobility impaired pedestrians --

- time to cross (i.e., duration of exposure to motor vehicles)
- amount of veer into or toward the street while crossing (ability to cross straight across driveway without veering toward or into the street)
- conflicts with vehicles
- perception of safety and comfort while crossing

for bicyclists, pedestrians --

- amount of time to perceive and react to vehicles approaching the bicycle or pedestrian paths
- time to cross (i.e., duration of exposure to motor vehicles)
- vehicles yielding to pedestrians and bicyclists
- perception of safety and comfort while crossing

Effects of Driveway Connection Transition Plan-Geometry on Turning Vehicles

Driveway plan-view geometry, from the perspective of motorists, includes driveway width, edge-transition shape (radius or taper), and the dimensions of the transition shape. For grouping purposes, angle-of-intersection and side-clearance are also included. The combination of these affects the speed and position of turning vehicles.

* Design objectives include:

1. minimize turning vehicles straying outside of the lane from which the turn is made
2. minimize turning vehicles overrunning the driveway edges
3. minimize turning vehicles straying into an oncoming driveway lane
4. minimize delay for through traffic and vehicles entering and exiting the driveway
5. minimize abrupt or erratic vehicle maneuvers
6. adequate side-clearance from signs, utility poles, mailboxes, and other roadside appurtenances

Exhibit 3-4 depicts some of the design objectives.

Note that “Driveway Plan-View Geometry” objectives may conflict with the preceding “Driveway Width” objectives. Designing for infrequent encroachment might not be desirable or cost effective in all cases. For instance, it may be quite acceptable for a large truck making a once-a-week delivery during light traffic to briefly occupy more than one lane. In situations where it may be appropriate to accept infrequent encroachments, the designer may need to address the resulting effects with measures such as strengthening the design of the immediately-abutting sidewalk so it will not crack under the load. The frequency with which it is acceptable to not meet these objectives (such as “How often can a turning vehicle encroach into an adjacent lane?”) is not precisely defined, but is affected by considerations such as the volume and speed of traffic on the roadway.

* From a motorist’s perspective, performance measures for how well the objectives are satisfied can be described by these related measures:

- frequency of turning vehicles straying outside of the lane from which the turn is made
- frequency of turning vehicles overrunning the driveway edges
- frequency of turning vehicles straying into an oncoming driveway lane
- speed of vehicles entering or leaving a driveway
- abrupt change of speed or trajectory of vehicles entering or leaving a driveway

As seen in Exhibit 3-5, even on newly-constructed driveways, these objectives are not always reached.

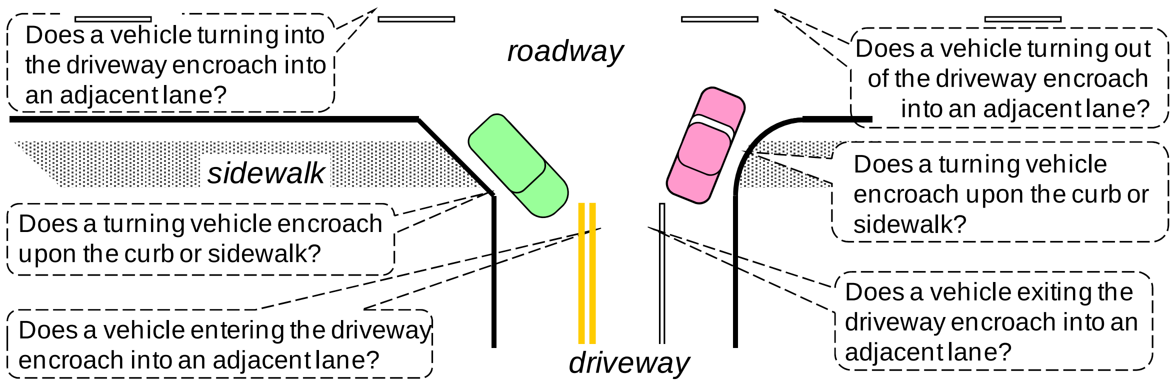


EXHIBIT 3-4 Driveway plan-geometry design considerations

EXHIBIT 3-5 Indicators of problems with driveway entry geometry

Driveway Throat Design

The driveway connection transition and throat act to affect many streams of traffic.

* Design objectives for the elements related to driveway throat (driveway connection) design:

1. not impeding or adversely affecting vehicular traffic on the intersecting roadway;
2. not impeding or adversely affecting pedestrian traffic on the intersecting sidewalk;
3. not impeding or adversely affecting bicyclists on the intersecting bike lane;
4. not impeding or adversely affecting internal on-site traffic operation
5. where warranted by driveway volumes or traffic controls, provide sufficient width for additional lanes, such as separate left- or right-turn egress lanes

As Exhibit 3-6 shows, if the distance between the driveway's intersection with the roadway and the first intersection or any other place where there are conflicting movements within the site is inadequate, the driveway is more susceptible to queuing in the driveway that can interfere with other traffic flows, and to conflicts with other vehicles, pedestrians, and bicycles that can lead to collisions. In order to reduce the frequency of queuing and conflicts, and to meet the preceding objectives, the designer provides a sufficient "access connection depth" or "throat length". For multilane driveways, length to accommodate vehicle lane change/weaving patterns is also needed. The designer should also attend to other driveway operational details, so that traffic on the driveway at or near the roadway does not backup or interfere with other traffic streams.

* Performance measures for how well the objectives are satisfied can be classified in the following categories along with the related measures:

for bicyclists and pedestrians --

- vehicles yielding to pedestrians
- conflicts with vehicles
- standing queue blocking sidewalk
- perception of safety and comfort while crossing

for motorists --

- delays or interference to motorists exiting onto the roadway
- delays or interference to motorists entering from the roadway
- vehicle speed or erratic movements while entering a driveway: It may be difficult to assess this effect alone, since other factors such as curb radius, driveway width, surface condition, and gaps in opposing traffic (for left-turning vehicles entering a driveway) also affect speed.

- Conflict/decision points are too close ⇒ insufficient reaction time.
- Inadequate length for vehicle queue in the driveway.

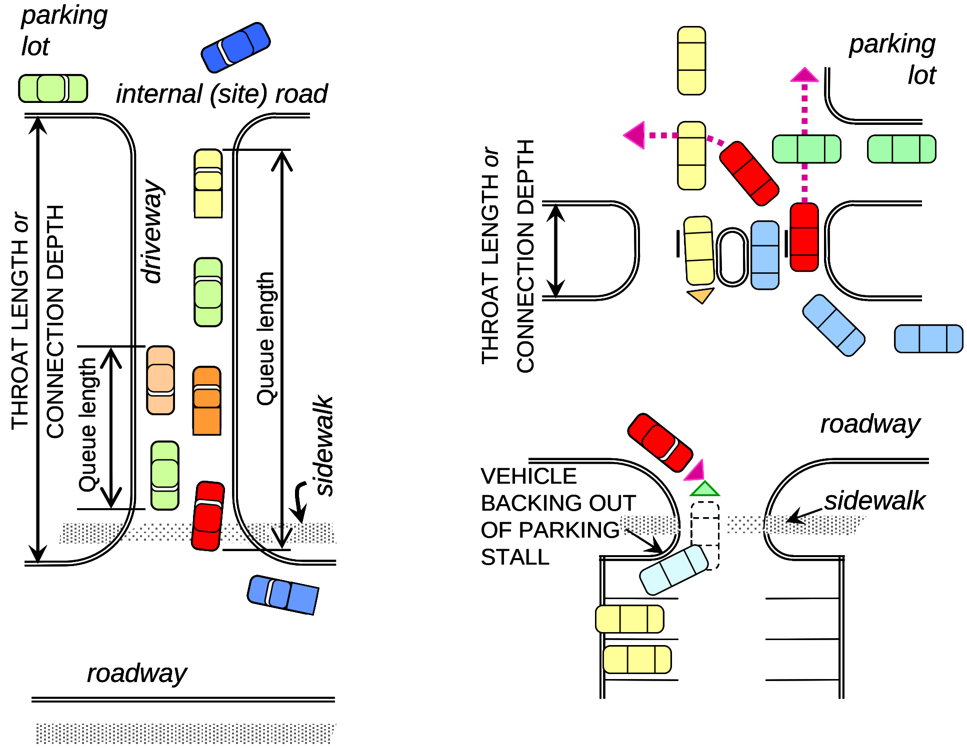


EXHIBIT 3-6 Driveway throat design issues

Driveway Border Design

The driveway border space is somewhat similar to the border of a street or highway.

* Design objectives for a driveway border can be those of pedestrians walking parallel to the driveway (into or out of the site), or of motorists using the driveway. The objectives include:

1. minimize pedestrian's exposure to motor vehicles
2. provide space for pedestrian movements that is usable in normal weather conditions (see Exhibit 3-7)
3. well-defined and visible driveway edges
4. adequate side clearance
5. no significant dropoff close to the edge of the lanes for motor vehicles

* Performance measures for how well the objectives are satisfied can be classified in the following categories, along with the related measures:

for pedestrians --

- number of pedestrian-vehicle conflicts
- condition of path surface in all common weather conditions
- perception of safety and comfort

for motorists --

- frequency and magnitude of encroachment outside of driveway lane
- frequency of vehicles departing the driveway

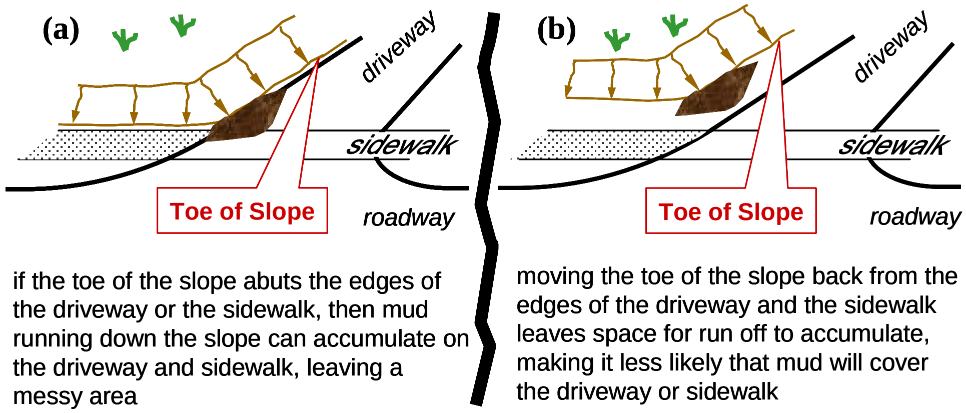


EXHIBIT 3-7 A seemingly-unrelated design factor can render the pedestrian space less usable

Channelization

Exhibit 3-8 shows three of the ways that islands can be installed to channelize driveways.

* Design objectives for channelization include:

1. separate conflicting movements (including opposing directions of travel)
2. control angle of conflict
3. reduce excessive pavement area
4. regulate traffic and indicate proper use of driveway/intersection
5. provide pedestrian refuge/protection
6. provide for protection and storage of turning and crossing vehicles

* Performance measures for how well the objectives are satisfied can be classified in the following categories along with the related measures:

for bicyclists, pedestrians --

- gap acceptance
- time to cross (i.e., duration of exposure to motor vehicles)
- area provided for pedestrian refuge
- extent of obstructions caused to bicycle traffic

- perception of safety and comfort while crossing

for wheelchair, cane, crutch, and walker users --

- subjective report of safety and comfort while crossing

for motorists --

- frequency of encroachment, driving outside of intended lane
- extent of encroachment
- angle and location at which vehicles merge, diverge, or cross
- area of vehicle conflict
- frequency of violation (e.g., driving around a triangular island to make an illegal left turn)
- perception of improved conspicuity, vehicle guidance
- crash rates

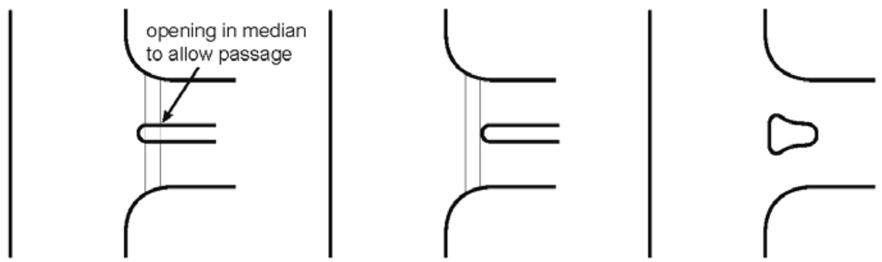


EXHIBIT 3-8 Driveway island types

Sidewalk Cross Slope

Where the sidewalk and the driveway cross, the sidewalk cross slope is the same as the driveway grade.

* Objectives of the design of sidewalk cross slope include:

1. not exceed the limits within which a disabled pedestrian can operate (meet ADA requirements of 2% cross slope)
2. not create undue hazard when frozen moisture is on the surface
3. provide adequate surface drainage
4. manage elevation change between the public road and internal site in an acceptable manner

* Performance measures for how well the objectives are satisfied can be classified in the following category along with the related measures:

for wheelchair, cane, crutch, and walker users --

- effort;
- comfort;
- control of mobility aid

Exhibit 3-9 depicts a driveway grade that creates excessive cross slope for the sidewalk.

[Note: the Access Board has funded a study to develop an appropriate methodology using "the various measures of energy use, effort, efficiency, and work utilized in human factors research today (SmartWheel, oxygen uptake; carbon dioxide expulsion; heart rate, user perceptions, etc.); and the physiological parameters of human performance (lactic acid threshold, resting/maximum heart rate, MET values, maximum power produced, etc)." per communication with Lois Thibault, U.S. Access Board, October 2006]

EXHIBIT 3-9 Excessive sidewalk cross slope at driveway

Driveway Grade and Vertical Alignment

Where the sidewalk and the driveway cross, the driveway grade is the same as the sidewalk cross slope.

* Design objectives for elements related to driveway grade and vertical alignment include:

1. manage elevation change between the public road and internal site in an acceptable manner
2. provide minimum grade to ensure drainage
3. avoid grade changes and vertical curves that would result in vehicle underclearance problems (i.e. vehicle getting hung up on driveway)
4. maintain reasonable speed for vehicle turning into or out of driveway

* Performance measures for how well the objectives are satisfied can be classified in the following category along with the related measures:

for motorists --

- crash history: It is expected that it would be rare for a vehicle hung up on the driveway to be involved in a crash with another vehicle, since at a driveway location, drivers are generally able to detect a stuck vehicle and bring their own vehicle to a stop. It can be hypothesized that if extremely slow entry/departure speeds attributable to sharp vertical geometry are leading to vehicle crashes, the causal factor may not be apparent to the investigating officer, and therefore the police crash reports will likely attribute the crash to failure to yield or something other than the driveway vertical geometry. These two considerations suggest that crash experience may not be a useful performance measure.
- incident reports: reflect calls for assistance to law enforcement agencies or towing companies;
- visible damage to the roadway or sidewalk surfaces: Gouges, scrapes and scratches in the concrete or asphalt surface (this will not necessarily reveal how frequently the problem occurs).
- vehicle speed entering or leaving a driveway: May be difficult to assess the effect of vertical alignment alone, since other factors such as curb radius, driveway width, surface condition, and gaps in opposing traffic(for left-turning vehicles entering a driveway) also affect speed.

Exhibit 3-10 shows examples of excessive driveway grades.

EXHIBIT 3-10 Examples of vertical alignment design problems

Roadway-Driveway Threshold Treatment

The threshold is the interface between the edge of the traveled way and the end of the driveway. When the roadway normally has a curb, the curbs are often modified in some manner at and near the driveway connection area..

*Design objectives for treating the street curb at the curb-driveway threshold include:

1. manage elevation change between the driveway and public road in an acceptable manner
2. maintain reasonable speed for vehicle turning into or out of driveway
3. manage surface runoff and confine the flow in the gutter

Exhibit 3-11 shows some of the more common treatments.

* Performance measures for how well the objectives are satisfied can be classified in the following category along with the related measures:

for motorists --

- vehicle damage. It may not be possible to correlate damage with a specific location.
- vehicle speed entering or leaving a driveway. May be difficult to assess the effect of vertical alignment alone, since other factors such as curb radius, driveway width, surface condition, and gaps in opposing traffic (for left-turning vehicles entering a driveway) also affect speed.
- driver discomfort: Perhaps best gauged by speed or change in speed near the curb-driveway interface.
- confine the drainage flow in the gutter within acceptable limits

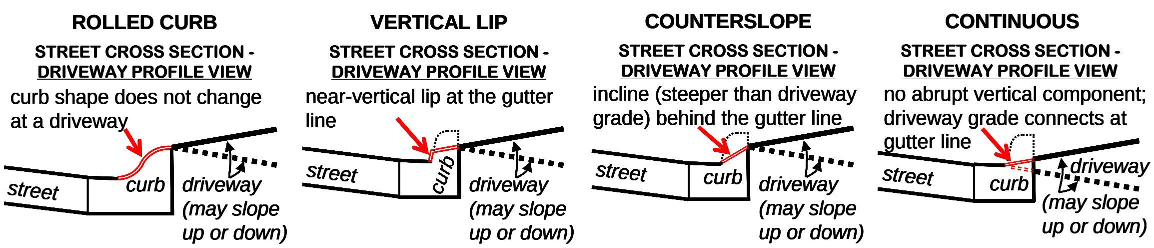


EXHIBIT 3-11 Examples of roadway-driveway threshold treatments

Driveway Visibility

There are three visibility relationships: (1) provide the user at the driveway (whether driver or pedestrian) with an adequate view of approaching traffic; (2) provide the user approaching the driveway with an adequate view of driveway traffic, and (3) for those users approaching the driveway and about to enter (vehicles) or cross (pedestrians) the driveway, provide an adequate view of the physical features of the driveway.

* Objectives of the design of elements related to driveway visibility include:

1. provide adequate sight distance for user exiting driveway
2. provide user approaching a driveway with an adequate view of driveway traffic
3. define edges of driveway to alert and better position drivers and pedestrians
4. minimize improper movements

Means to accomplish these objectives include analyzing the location of walls, planters, signs, street furniture, etc., and the use of contrasting elements.

* Performance measures for how well the objectives are satisfied can be classified in the following categories along with the related measures:

for all users --

- sight lines (consider different size vehicles and different users, including those exiting the driveway, those turning into the driveway and those continuing past the driveway)
- vehicles yielding to others (bicyclists, motorists, pedestrians)
- perception of safety and comfort while crossing

for motorists --

- sight distance from driveway
- distance at which driver on intersecting road perceives driveway
- distance at which users approaching a driveway and about to enter (vehicles) or cross (pedestrians) the driveway have an adequate view of its physical features
- improper movements (e.g. lane changes at last minute to access driveway)

Auxiliary Lanes for Right-Turn Entry Movement into Driveways

At some driveways, an auxiliary right-turn lane is provided for vehicles about to turn into the driveway.

* Design objectives for the elements related to the auxiliary right-turn lanes include:

1. remove right-turning vehicles from the through traffic lanes, to minimize delays and crashes from driveway access and egress maneuvers to and from the roadway
2. maintain safety and visibility for pedestrians and vehicles
3. provide for adequate traffic operations (i.e. reasonable traffic delay) on driveway approach

* Performance measures for how well the objectives are satisfied can be classified in the following categories along with the related measures:

for bicyclists and pedestrians --:

- gap acceptance (i.e. duration of waiting to cross driveway or cross-street)
- time to cross (i.e., duration of exposure to motor vehicles)
- perception of safety and comfort while crossing

for motorists --

- vehicle speed entering or leaving a driveway. It may be difficult to assess this effect alone, since other factors such as curb radius, driveway width, surface condition, and gaps in opposing traffic (for left-turning vehicles entering a driveway) also affect speed;
- headways in curb lane;
- effects of vehicles entering and exiting the driveway on through traffic (may be measured in terms of percent of through vehicles impacted by right turn (as a function of right turn volumes); probability of right turn through vehicles impacted at least once per quarter mile; and/or percentage of right turn vehicles impacted at or beyond another driveway)

Drainage of Surfaces Occupied by User Groups

Runoff from precipitation can affect the usability of the driveway-roadway connection area by the various user groups.

* Design objectives for the elements related to driveway drainage typically include creating a system that results in adequate confinement, redirection, or removal of surface runoff, so as to:

1. minimize runoff accumulation of such magnitude that it becomes an impediment to bicyclists, drivers, or pedestrians
2. minimize the frequency of right-turning vehicles straying from their lane or overrunning the right edge due to the accumulated runoff obscuring lane and edge definition indicators
3. not adversely affect the speeds of vehicles turning into or out of the driveway
4. minimize the possibility of highway drainage from overtopping the driveway, flowing onto private property
5. minimize the possibility of drainage from private property flooding the roadway

* Performance measures for how well the objectives are satisfied can be classified in the following categories along with the related measures --

for bicyclists and pedestrians --

- depth or velocity of flow
- time to cross (i.e., duration of exposure to motor vehicles)
- frequency of standing water covering the usual cues (curb edges, etc.), making it difficult for the bicyclists or pedestrian to identify edges
- perception of safety and comfort while crossing

for motorists --

- depth or velocity of flow
- no disruption to driving, such as splash momentarily obscuring vision
- frequency of standing water covering the usual cues (curb edges, etc.), making it difficult for the driver to identify pavement edges
- frequency of driving over the right edge or outside of the lane
- vehicle speed entering or leaving a driveway: May be difficult to assess this effect alone, since other factors such as curb radius, driveway width, surface condition, and gaps in opposing traffic (for left-turning vehicles entering a driveway) also affect speed.

Spacing Between Driveways

The spacing between driveway connections is one aspect of access management.

* Design objectives for the elements related to driveway spacing include:

1. minimize conflicts at and near the driveway intersection with the public highway
2. minimize conflicts between traffic flows at the driveway and traffic flows at nearby upstream and downstream driveways/intersections
3. maintain operations along the intersection street/arterial at a level consistent with its function
4. provide sufficient separation distance so the roadway or sidewalk user does not have to monitor more than one driveway at a time
5. minimize driver confusion regarding proper driveway entrance for ultimate destination

* Performance measures for how well the objectives are satisfied can be classified in the following categories along with the related measures:

for bicyclists, pedestrians --

- user does not have to monitor traffic on more than one driveway at a time
- frequency of conflicts involving avoidance maneuvers
- perception of safety and comfort while crossing

for motorists --

- user does not have to monitor traffic on more than one driveway at a time
- number of conflict points and volume of conflicting traffic movements
- vehicle speed entering or leaving a driveway
- driveway crashes by type/severity, including both totals and per driveway
- crashes (may be measured in terms of crash rate per vehicle-mile, crash rates expressed as the product of conflicting vehicle volumes, and/or crashes per entrance)
- frequency of evasive maneuvers

3.2 EVALUATE THE CURRENT STATE OF PRACTICE

The survey of agencies, review of literature, and other work performed in Task 1 identified current practices and provided insight into a wide range of issues related to the geometric design of driveways. The work performed in Task 2 produced a long list of factors that can affect the operation of driveways, and therefore may merit consideration when a driveway is under design.

Some issues have been studied and the findings are documented. Other issues, while they may have been previously addressed, may not currently be developed in a way that fully satisfies the needs or demands of the various user groups. Several topics that could benefit from additional study and analysis emerged from these tasks, and they were discussed in detail in a draft report to the project oversight panel; they are briefly summarized in the following sections.

1. Analysis of Driveway-Influenced Crashes

An analysis of crash data details can lead to better insight into what user groups and traffic (motor vehicle, bicycle, and pedestrian) conflict patterns are or are not experiencing elevated numbers and severities of crashes. Without this type of information, identifying which scenarios really are problematic, identifying which user groups are more at risk, and prioritizing conflicting needs becomes a speculative exercise.

A few studies of driveway crash attributes have been conducted. An examination that included a significant component of data from a dense urban area seemed to be absent.

2. Visual and Tactile Cues to Identify the Pedestrian Route Across the Driveway

Visually-impaired pedestrians on a sidewalk find it more difficult to cross driveways they encounter when the driveway is wide and the surface of the intended path or route across the driveway does not contrast with the surrounding surfaces. The additional contacts made as part of Task 1 activities elicited a response that identified this need. The respondent called for field tests of techniques to improve the wayfinding abilities of visually impaired pedestrians as they cross wide driveways.

3. Width of Driveway to Cross (from a pedestrian's perspective)

Some aspects are in need of basic research to define human performance measures, while other aspects could be partially addressed by research on other topics.

4. Effects of Driveway Plan-Geometry on Turning Vehicles

Field tests to observe the effects of entry shape and dimensions on speed and position patterns of vehicles entering or leaving a driveway have been conducted in Texas, and more recently in Oregon. Related tests have been performed for trucks and buses. Of the four driveway turning movement, the right turn entry has been the subject of more effort in the past studies. Given that exiting vehicles often are required to yield the right of way and stop, and entering left-turning vehicles yield to oncoming traffic, the emphasis on right-turning vehicles entering a driveway is probably a good choice as long as research funds are limited. A significant challenge and limitation has been the difficulty of capturing the speed vector of a vehicle turning on a short radius. Research that employs newer technology could produce new and more-detailed findings.

5. Driveway Throat Design

Driveway throat design addresses both connection depth and width. Existing research and guidelines address these to some degree. At a specific location, the actual requirements are greatly affected by the trip generating patterns of the site, and the traffic control operations at the driveway-roadway intersection.

6. Driveway Border Treatments

The research team members did not find any previous in-depth material that addressed factors past the edge of the driveway, such as sidewalks parallel to the driveway, clearances from retaining walls, side slopes, etc. However, there seems to be greater concern directed toward a number of other elements than toward driveway border design.

7. Channelization

Triangular islands ("pork chops") have been constructed at driveway intersections with both divided and undivided roadways to discourage or prohibit one or both left turns. More information is needed about their effectiveness and how they may be designed to improve their effectiveness. Design questions relate to the shape, size, and radius of these triangular islands. Research could involve comparisons between different designs in similar locations or before-and-after studies.

8. Effects of Sidewalk Cross Slope on the Mobility Impaired

Although the validity of the current 2% maximum cross slope rate has been questioned, even if a future study were to justify a greater rate, changing the current 2% maximum would require revisions to the practices that are associated with the Americans with Disabilities Act.

9. Vertical Profile Controls

Vehicles continue to hang up on abrupt driveway vertical alignments, and the sidewalk cross slope flattening requirements of the ADA added complexity to the issue. It seems worthwhile to re-examine the vertical geometry needed to avoid vehicle-underside hangups. A design passenger car should be one of the vehicles emphasized in a new study.

10. Roadway-Driveway Threshold Treatment

It would be worthwhile to investigate the degree to which a vertical lip at a driveway truly is an impediment. However, other issues seem to be more urgent at this time.

11. Driveway Visibility

Driveway visibility is important to help guide motorists to turn into the proper location to access a site, especially when there are higher volumes and speeds on a main roadway that could be adversely affected by drivers confused or slowing down. Research could be done on driver perceptions and visibility of approaching driveways that would help answer the question of what design features at a driveway make it more visible.

12. Auxiliary Lanes for Right-Turn Entry Movements into Driveways

The literature suggests the need for deceleration lanes when right-turn volumes into a driveway are heavy and/or could have a significant adverse effect on through traffic. One objective of NCHRP Project 3-72 is to develop design guidance for addressing the safety and operational tradeoffs of right-turn deceleration lanes at driveways and unsignalized intersections. Further study could be done in NCHRP Project 15-35 to identify the impact that a deceleration lane has on the dynamics between right-turning vehicles into a driveway and pedestrians crossing the driveway.

13. Drainage of Surfaces Occupied by User Groups

When compared to the range of current driveway design issues, the problems associated with driveway surface drainage seem to be relatively minor. Some of them would be difficult to meaningfully quantify.

14. Spacing Between Driveways

Studies, while certainly not exhaustive, have addressed this issue, which is more closely aligned with the topic of access management.

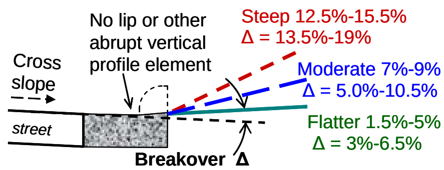
3.3 PROPOSE AND SELECT RESEARCH ACTIVITIES

In Task 4, the contractor suggested that for Phase 2 research activity, the project oversight panel consider and select from among the following topics.

1. Analysis of Driveway Influenced Crashes
2. Visual and Tactile Cues to Identify the Pedestrian Route Across the Driveway
3. Effects of Driveway Plan-Geometry on Turning Vehicles
4. Driveway Triangular Islands
5. Vertical Profile Controls

During Task 5, the project oversight panel discussed various options, and then selected research activities related to the design of the vertical alignment of driveways to be conducted during Task 6A in Phase 2 of the project. Exhibit 3-12 summarizes the nature of these activities.

EXHIBIT 3-12 Summary of project research objectives

Objective	Description of Work	Additional Information
1. Determine the crest and sag grade changes at which a static vehicle drags the underside.	Analyze the ground clearance of three or four selected vehicles. The contractor analyzed five (one additional) vehicles. Measurements for the pickup truck and trailer were obtained from manufacturers' literature. All others were measured by the contractor.	P-car: Chevy Camaro, Corvette Ford F-150 pickup w/trailer Class A diesel motor home Tractor w/10-bay beverage trailer
2. Determine what actual driveway profiles cause the undersides of vehicles to drag.	Measure driveways that have a visible indicator of a vertical alignment problem. The contractor found driveways with scrape or gouge marks on the pavement surface, near where the driveway intersects the street, then measured the driveway profile.	
3. Assess the effects of angle changes (roadway cross slope – driveway grade) at the roadway-driveway interface and driveway grades on the speed and elapsed time of vehicles turning left and turning right into a driveway.	The contractor located a pool of driveways similar in many respects, but with different grades, then measured speeds and elapsed times of vehicles turning into the driveways. The driveway were assigned to the following three grade groups: • steeper grades (12.5%-15.5%, breakover 13.5%-19%) • moderate grades (7%-9%, breakover 5%-10.5%) • flatter grades (1.5%-5%, breakover 3%-6.5%)	 The speeds and elapsed times for vehicles turning right and turning left in to the three driveway grade groups were compared to determine what effect grade has. This is related to both the exposure of turning vehicles to crashes due to speed differential, and exposure of sidewalk users to turning vehicles.

CHAPTER 4
Data Collection and Analysis

The issues related to design of the vertical alignment of driveways that were selected for study fall into the following three categories.

- Driveway grades and measured vehicle ground clearance
- Driveway grades and signs of inadequate ground clearance
- Driveway grades and speeds of entering vehicles

The following sections in this chapter discuss the procedures and findings from the Task 6A research activities.

4.1 DRIVEWAY GRADES AND MEASURED VEHICLE GROUND CLEARANCE

There are two modes in which the underside of a vehicle can drag or hangup. One mode occurs when the road profile creates a sharp vertical crest, which causes the underside of the vehicle between the front and rear axles to drag on the pavement surface. The other mode occurs when the road profile creates a sharp vertical sag, which causes the underside of the vehicle either to the front of the front axle or to the rear of the rear axle to hang up. Exhibit 4-1 displays both of these conditions.

To determine the change in vertical profile at which the underside of the vehicle will drag, one makes x- and y-coordinate measurements of the critical points on the underside of a vehicle that will define a profile or silhouette of the vehicle's underside. Then one conducts a geometric analysis to determine the least change in profile grade that will cause the underside of the vehicle to come in contact with the driveway surface. Exhibit 4-2 displays the geometry of this analysis.

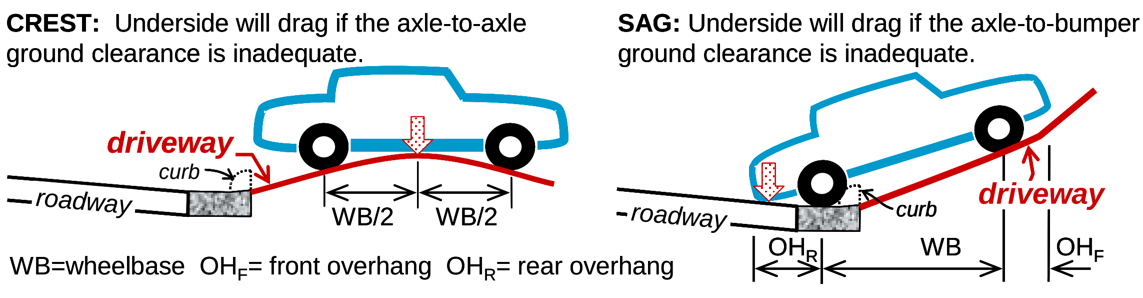


EXHIBIT 4-1 Two modes of vehicle underside dragging

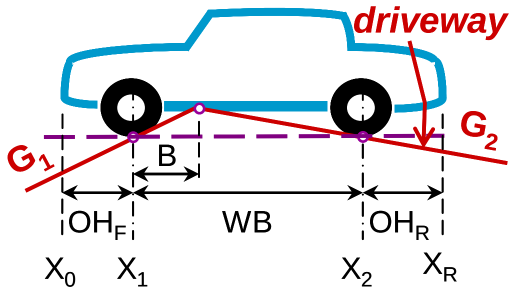


EXHIBIT 4-2 Vehicle ground clearance geometry

Selecting and Locating Vehicles

The project oversight panel directed the contractor to define the ground clearance dimensions of at least three vehicles, and a fourth if the budget allowed. The project oversight panel specified that the vehicles to be defined include a small automobile and a Class A motor home (“diesel pusher”), and the contractor suggested a pickup truck pulling a trailer and a beverage delivery truck.

To locate vehicles to measure, the contractor contacted nearby automobile dealers, beverage distributing companies, and recreational vehicle dealers. The ground clearance of one automobile was measured on a dealer's lot, and another was measured on a dealer’s showroom floor. The beverage delivery truck was measured inside the distributor’s warehouse. The motor home was measured on a dealer's lot. Dimensions for the pickup truck and trailer were obtained from manufacturers’ literature.

Measuring Vehicle Ground Clearances

To measure the underside in hard-to-reach areas, a technician fabricated a specially designed measuring jig. This jig, shown in Exhibit 4-3, consisted of a black rigid flat base, a silver vertical rod at each end of the base, and an orange rigid parallel bar with bushings on each and that allowed the bar to slide up and down on the two vertical rods. To measure the vertical clearance at any given spot, two people slide the rigid parallel bar up to contact the underside of the vehicle, then make a measurement from the ground up to the top of the rigid bar.

EXHIBIT 4-3 Measuring vehicle ground clearance

Vehicle Ground Clearance Measurement Findings

Exhibit 4-4 shows the resulting x- and y-coordinates of the points that define the underside profile of the four measured vehicles. From these measurements, the profile or grade change at which the vehicle would drag in both crest and sag conditions was computed.

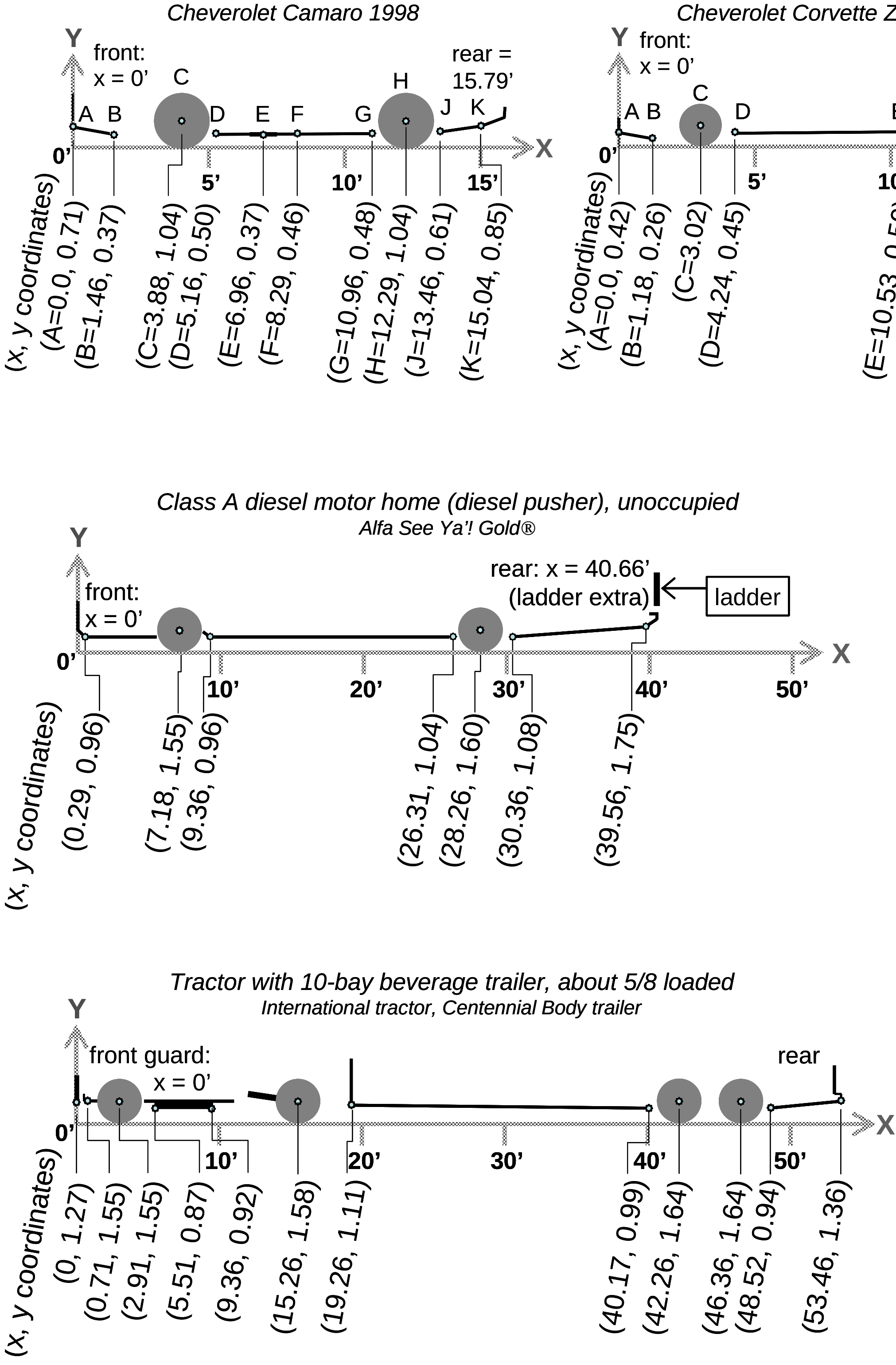


EXHIBIT 4-4 Measured coordinates of vehicle undersides

4.2 DRIVEWAY GRADES AND SIGNS OF INADEQUATE GROUND CLEARANCE

Visible scrape marks on the surface that result from the dragging of vehicle undersides can be clear indicators that the profile geometry of an existing driveway is too abrupt. The project oversight panel directed the contractor to measure the profiles of driveways with scrape marks that the contractor encountered during the course of conducting the research.

A few of these driveways were measured by one person with a 24-inch digital level, while most of them were measured by two-person crew with land surveying equipment. Often, two profiles were measured. For instance, for driveway with visible scrape marks on the entry side, the entry-side edge and the driveway centerline were profiled. One of the driveways with visible scrape marks that the contractor measured is shown in Exhibit 4-5.

EXHIBIT 4-5 Example of a driveway with visible vehicle underside scrape marks

The crest and or sag breakover angles near scrape marks on each driveway were calculated. For those driveways with a crest breakovers close to a sag breakovers, the investigator was not able to determine with certainty if the scrape marks were the result of the crest or the sag profile. The 31 driveways that were measured are listed in the Exhibit 4-6. The individual data forms for each measured driveway are presented in Appendix F.

EXHIBIT 4-6 Driveways with visible scrape marks that were measured

	Street	Block	Site Name	Notes	Breakover Grade	
					Crest	Sag
AUSTIN						
1	Balcones	N 5206	Highland Park Baptist Church	south exit drive	na	16.8%
2	First		HEB shopping center	west drive	na	**9.4%**
3	Hancock	W 3339	Russells' Bakery	continuous drive	na	21.3%
4	William Cannon	W 1021	Genie Car Wash	west drive	na	17.0%
5	William Cannon	W 2501	Stonegate One, medical offices	middle drive, above the sidewalk	na	13.5%
FAYETTEVILLE-SPRINGDALE						
6	Cliff		Aqua, multifamily		na	**8.6%**
7	Cliff		Lapis, multifamily		**11.3%**	13.4%
8	Cliff		E Peridot, multifamily		na	15.1%
9	Crossover	N 1831	Automatic Car Wash	south driveway	16.5%	na
10	Dickson	W 800	SE Building, classrooms		na	11.1%
11	Gregg	S 41	Myers' Apartments		na	**10.2%**
12	Hyland Park	2730	single-family residence		na	> 20%
13	Lafayette		Valero, gas station	middle drive	**10.6%**	18.5%
14	Mission	1813	Tim's Pizza	west drive	na	11.2%
15	North St		North Street Condos		**10.9%**	na
16	Rock Cliff	583	single-family residence		na	> 20%
17	Rock Cliff	599	single-family residence		na	> 20%
18	St Charles		Colliers' Drug		na	14.4%
19	Sapphire		Aqua, multifamily		13.9%	na
20	Sapphire		Goldrush, multifamily		14.2%	12.6%
21	Sixth		O'Reilly's	east drive	16.5%	na
22	Sunbridge	W 6	Arthritis Center		13.1%	na
23	Sunbridge	E 18	McClelland's Fly Shop		**11.4%**	17.2%
24	Sunbridge	E 114	Sunbridge Center		12.0%	na
25	Sunbridge	E 158	VA Dental		**? 9.7%**	13.9%
26	Sunbridge	E 180	VA Outpatient		**11.4%**	14.2%
27	Sunset	2255	Fuji Restaurant	west drive	14.0%	na
28	Sycamore		Royal Cleaners	west edge	na	20.0%
TULSA						
29	71st	E 6550	Hausam Realty, Arvest Bank		? 9.0%	16.4%
30	Archer	E 6616	Super 8 Motel		na	16.9%
31	Mingo		Union Plaza shopping center	west drive	**?10.5%**	16.8%
			Minimum Observed Breakover Grade		10.6%	8.6%

The vehicle geometry that causes the undersides of vehicles to drag on the pavement surface is a combination of ground clearance height and either the wheelbase or the overhang length. Obviously, there are many possible combinations of height and length that could cause the underside to scrape the pavement surface. The driveways at which these measurements were made are traversed mainly by private automobiles and similar sized vehicles. When determining the grade on either side of a breakover point, the contractor often computed the average grade of the driveway surface within four to eight feet of the scrapes or the breakover point.

4.3 DRIVEWAY GRADES AND SPEEDS OF ENTERING VEHICLES

Most of the research activity was directed toward measuring and comparing the speeds and elapsed times of vehicles turning right and turning left into driveways having different vertical alignment or profiles. The project oversight panel had directed the contractor to examine this aspect of traffic operations because of the perspectives of various interest groups. Some advocates for bicyclists, pedestrians, and pedestrians with disabilities are concerned that vehicles enter driveways at speeds they consider excessive and create a hazard. On the other hand, those focusing on motorists' are concerned that the more time it takes for a vehicle to enter a driveway, the more exposed that vehicle is to being struck by other through vehicles. So there are the following two underlying questions.

1. To what extent does the vertical alignment affect the speed and the elapsed time of vehicles turning right or turning left into a driveway?
2. What effect do these differences have on the exposure of all users (bicyclists, motorists, pedestrians, pedestrians with disabilities)?

Criteria for Suitable Sites

The researchers determined that the sites selected for the study of speed and elapsed time as vehicles entered driveways of different grades should possess attributes that are representative of a broader population of driveways. To the extent possible, the various driveways selected should have somewhat similar attributes, in order to reduce the variability among the attributes of the sites at which the data would be collected.

Even though it was theoretically desirable to find sites having the same widths, entry shapes, and shape dimensions, the researchers recognized that it was highly unlikely that this could be perfectly achieved. It was decided that one factor that could increase the similarity among the sites, in terms of characteristics such as volume and speed of traffic on the through street, would be to select some driveways along the same street.

The researchers developed an initial set of criteria for identifying potentially suitable driveways for data collection. The criteria evolved during the course of the search, with some of the evolution affected by what traits were more frequently encountered. The following criteria helped identify a pool that is typical of those driveways serving small- to medium-sized commercial and professional office developments that became quite common in the latter part of the 1900s along non-fringe suburban multilane arterial roadways. The term "non-fringe suburban" was selected to indicate land that was not at the edge of the developed urban area, where conditions approach those of an open, rural highway, yet not in or near the downtown urban core, where speeds are typically lower and congestion is greater.

General Traits

1. The site has space to accommodate people and equipment collecting the data, with a clear line of sight to the driveway entry
2. The driveway has sufficient volume to make the time spent in data collection productive
3. The driveway is not built to appear like a street (note: this tends to exclude driveways to large commercial developments, such as large shopping centers)
4. Through-street posted speed limit is 40 or 45 mph

Plan View Design

5. Driveway is either 2 or 3 lanes wide
6. The driveway does not have pavement markings that would conflict with the standard marking the contractor installs at each site
7. Driveway throat length (connection depth) is not less than 23 ft, measured from face of curb
8. Driveway entry transition shape is curved (i.e, not tapered/triangular) with a radius of 13 to 19.5 ft
9. Driveway intersects street at or close to a 90^{O} angle
10. Both the driveway and the through-street are fairly straight in the immediate vicinity of where they connect
11. Driveway connects to a multilane street
12. The width of the through-street outer lane from curb face to lane line is between 10.5 and 13.5 ft (e.g., no shoulder, bike lane, or auxiliary right-turn lane)
13. The through-street has a separate left-turn lane or a two-way left-turn lane (TWLTL)

Vertical Alignment

14. No vertical lip at the roadway-driveway interface
15. The driveway does not slope markedly downward from the through-street into the site
16. The street grade is relatively flat, not steep

Operations - Driveway Interaction with Other Traffic
17. Driveway is not signalized
18. Driveway traffic operations are not often affected by a nearby traffic signal, such as the backup queue from a nearby signalized intersection
19. Enough separation so driveway traffic is not often affected by any other driveway or street

Searching for Suitable Data Collection Sites

Searches were conducted for driveways suitable for data collection in the following locales.
Arkansas: Bentonville, Fayetteville, Rogers, Russellville, Siloam Springs, Springdale
Missouri: Springfield
New Jersey: Montville, Parsippany, Wayne
New York: Roslyn Heights, Yonkers
Oklahoma: Broken Arrow, Jenks, Sapulpa, Tulsa
Texas: Austin

The process of searching for suitable data collection sites and making detailed inspections and measurements lead to the following observations about driveways.

Some driveway plan design elements, as constructed and in-place, are irregular. Specifically, highly irregular and variable entry radii were encountered. A common manifestation of this was a curved entry shape in the form of a spiral, not a curve with a constant radius. This caused some potential sites to be excluded from further consideration.

Driveway grades are seldom constant across the width of the driveway. This is inherent in the geometric nature of one plane surface (the driveway surface) intersecting another plane surface (the edge of a roadway) on a grade. Unless the cross slope of the driveway exactly follows the grade of the street, laws of geometry cause the driveway grade to vary across the width of the driveway.

In some areas, it may be common practice to construct the outer one to two feet of the outside lane (i.e., gutter area) with a greater cross slope than that of the rest of the lane. Since this construction practice makes it difficult to quantify the street cross slope and the actual grade change perceived by the driver at the street-edge interface with the driveway-end, otherwise desirable sites were excluded from further consideration due to the increased gutter cross slope.

Even though a designer may specify a measurement to a hundredth of an inch, roadway construction is seldom that precise. This is not to imply that designers should be less precise; rather it is to state that an expectation of construction to that precision is unrealistic. And even if a roadway were constructed with a high precision, settling or other material deformation would eventually bring about a change of dimensions. Specific to this study, the researchers observed that the rutting and shoving of asphalt concrete surfaces created slight variations in the cross slope over the width of a lane.

Selecting Suitable Data Collection Sites

Recognizing that the only way to obtain a perfect set of data collection sites would be to fund and construct the driveways specifically for this project, the researchers exercised judgment to evaluate potential driveway sites. After conducting visual inventories along many miles of roadway in a number of cities, a candidate short list of driveways with relatively similar characteristics evolved.

All of the selected driveways serve small to medium-sized commercial or office tracts abutting non-fringe suburban arterial roadways with speeds of 40 or 45 mph. (At one driveway site, either the posted speed limit was incorrectly noted during an initial search, or the speed limit was changed to 50 mph.) All of these driveways connect to multilane (4 or 6 through lanes) arterials with either a raised median or a two-way left turn lane (TWLTL).

After considering the various attributes associated with the driveway sites on the candidate list, certain sites were selected for actual field data collection and analysis. The researchers measured driveway attributes such as width, entry radius, and profile grades at each site.

The sites selected in Austin, Texas were all along the same arterial roadway. The sites selected in Tulsa and in the suburb of Broken Arrow, Oklahoma were all in the southeast part of the metropolitan area, where Tulsa and Broken Arrow abut. One of the sites was in Fayetteville, Arkansas. The selected driveways were grouped into one of three categories shown in Exhibit 4-7.

- The steeper driveways have grades up from the gutter line of 12.5% to 15.5%, with changes of grade between roadway cross slope and the driveway grade (i.e., breakover) between 13.5% and 19.0%.
- The moderate-grade driveways have grades up from the gutter line between 6.0% and 9.0%, with breakovers between 5.0% and 10.5%.
- The flatter driveways have grades up from the gutter line between 1.5% and 5.0%, with breakovers between 3.5% to 6.5%.

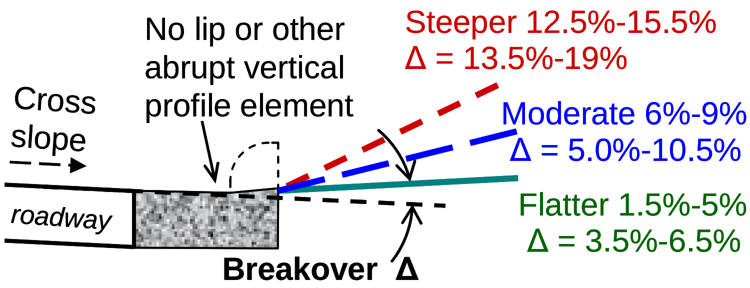


EXHIBIT 4-7 Driveway grade groups

Exhibit 4-8 lists the sites selected for study. Exhibit 4-9 shows example site photographs. Photographs of all sites are in Appendix G.

EXHIBIT 4-8 Driveways selected for speed and elapsed time studies

Site Description	Street Alignment	Speed Limit (mph)	Outer Lane Width (ft) See Note	Street Cross Slope	Grade Change Near Gutter Line	Dway. Grades	Throat Length (ft)	Throat Entry Traffic Pattern	Rt. Turn Entry Radius (ft)	Dates of Studies
STEEPER										
Stonegate One - Austin Pain Assoc.	Straight, G ≈ 2.6%	40	11.0	-3.1%	18.6%	15.5% 6.5' / 0.3% 6' / 13.8%	48	turn conflict	19	Sep 18 Jan 7 Jul 29
Genie Car Wash	Straight, G ≈ 0.6%	40	11.2	-4.2%	17.0%	12.8% 2' / 15.6%	23	turn conflict	19	Sep 15 Jan 5
Union Plaza - Mardells	Straight, G ≈ 1.6%	40	13.5	-2.6%/ -7% 1'	15.8%	13.2% 4' / 3.4% 6' / 5.3% 8'	48	thru free	13.5	Feb 9 Mar 15
Arvest Bank	Straight, G ≈ -1.2%	40	12.6	-1.2%	13.8%	12.6%	29	thru free	16	May 13
MODERATE										
Okla. Central Credit Union	Straight, G ≈ 0.4%	45	11.5	-1.8%	10.5%	8.7% 10' / 12.8%	66	mixed free	18	Mar 14
McAlisters, Meineke	Straight, G ≈ -1.0%	45	13	-3.8%/ -1%	10.1%	6.4% 12' / 5.5%	64	turn free	16	Aug 12
small shopping center- HEB grocery	Straight, G ≈ -2.4%	40	11.0	-4.0%	10.0%	6.0% 10' / 1.1%	41	thru conflict	13	Sep 16
Hollywood Video - Southcross Plaza	R=2292 ft, G ≈ -0.5%	40	11.5	2.0%	5.1%	7.1% 6.5' / 2.2% 4.5' / 0%	29	turn conflict	17	Sep 17 Jul 30
FLATTER										
Wendys	Straight, G ≈ -0.6%	45	13	-2.1%	6.5%	4.4% 11' / 1.3%	40	turn free	15.5	Nov 16 May 14
J D China	Straight, G ≈ 0.0%	40	11.5	-0.5%	5.2%	4.7% 20' - 2.0% 6'	43	thru free	19	Feb 27 Jul 1
Shell gas; self storage	Straight, G ≈ -0.9%	40	12.0	-2.0%	5.0%	3.0% 9' - 0.8%	52	turn conflict	19.5	Jan 6
Red Robin	Straight, G ≈ -0.4%	45	11.5	-2.1%	3.7%	1.6%	58	turn free	19.5	Mar 16

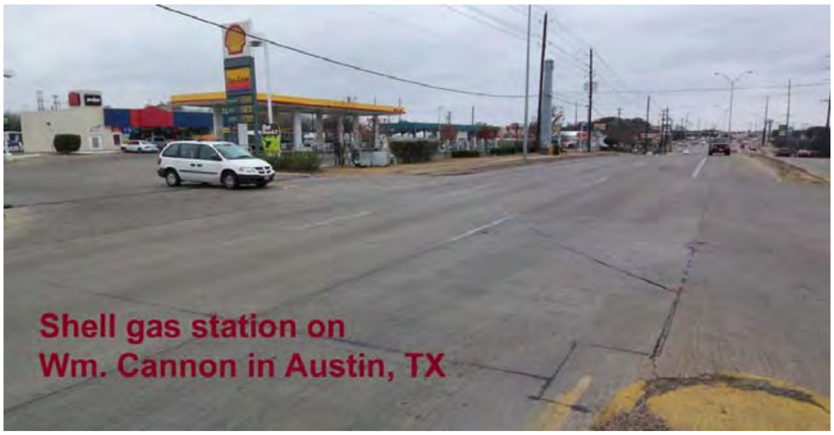


EXHIBIT 4-9   Examples of speed data collection sites

Descriptions of Steeper Sites

The Stonegate One professional offices in Austin consist of a series of upscale looking buildings in a strip mall arrangement. The driveway at which data were collected serves medical offices. Stonegate One is on West William Cannon Drive, which has four lanes and a raised median. This roadway is abutted by mostly small- and medium-sized commercial and office tracts. The vacant tract across the street was undergoing site grading and construction when data were collected.

Genie Car Wash in Austin offers both self-service and attendant car washes on a stand-alone tract. It is on West William Cannon Drive, a six-street roadway with a raised median. Due to the raised median, only right turn movements into the site are possible. The roadway is abutted by mostly small- and medium-sized commercial and office tracts. In the immediate area, a multifamily area and the back side of some single family lots abut the street. One-story professional offices are across the street.

Union Plaza shopping center is a medium-size center occupying the northeast corner of South Mingo and East 71st in Tulsa. It is anchored by a large hobby-and-crafts store and a large bookstore. The driveway at which data were collected is on Mingo, a four-lane roadway with a TWLTL. In the immediate vicinity, South Mingo is abutted by a variety of commercial land uses, and a high school and a large church building. (Note that at this site, data were collected on Saturday.) Across the street, there are small stores on outparcels, with a large discount store behind them.

The Arvest Bank branch office is on the northeast corner of East 61st and 89th East in Tulsa. The tract is connected to one adjacent site, a small one with commercial tenants. The driveway at which data were collected is on East 61st, a four-lane roadway with a TWLTL. This roadway is abutted by mostly small commercial and professional sites. The playground for a school is across the street.

Descriptions of Moderate Sites

The Oklahoma Central Credit Union branch in Broken Arrow occupies a stand-along site on South Aspen, a four-lane roadway with a TWLTL. The roadway is abutted by mostly small- and medium-sized commercial and office tracts. The tract to the south (behind the field of view in the photograph) is vacant. Across the street, there is a one-story thrift store.

McAlister’s Deli in Broken Arrow shares a driveway with a Meineke Car Care Center to the south. It is on Aspen, a four-lane roadway with a TWLTL. The roadway is abutted by mostly small- and medium-sized commercial and office tracts. A Walmart is behind the site, and a car wash is across the street.

The small shopping center on the northeast corner of West William Cannon Drive and South First in Austin is anchored by a HEB grocery store. The driveway at which data were collected is on Cannon, which has six lanes and a raised median. Cannon is abutted by mostly small- and medium-sized commercial and office tracts.

Hollywood Video in Austin is one of the many tenants in Southcross Plaza, an approximately ¼-mile long strip center along West William Cannon Drive, which has six lanes and a raised median. The roadway is abutted by mostly small- and medium-sized commercial and office tracts. Some of the land across the street in undeveloped, and some is occupied by a shopping center with a grocery store.

Descriptions of Flatter Sites

Wendy’s Restaurant in Tulsa is connected to other commercial tracts on the south side of East 71st Street, which has six lanes and a raised median. The roadway is lined on both sides by a variety of commercial uses.

J. D. China Restaurant is on a stand-along tract on West 6th Street, a four-lane roadway with a TWLTL, in Fayetteville. The roadway is in an area lined on both sides by mainly small commercial tracts. The tract immediately across the street is occupied by a hardwood mill, with a solid wood fence along the right-of-way line.

The Shell gas station and the self-storage units share a driveway on the south side of East William Cannon Drive in Austin, and the driveway is also connected to a strip shopping center to the east. Cannon has six lanes and a raised median. The roadway is abutted by mostly small- and medium-sized commercial and office tracts. In this section, apartment complexes are across the street.

The Red Robin Restaurant is on the south side of Kenosha in Broken Arrow (an extension of E. 71st in Tulsa), a four-lane roadway with a TWLTL. The tract is connected internally to a tract to the east. The roadway is abutted by a variety of commercial tracts on both sides. The tract immediately to the west (to the right in the photograph) is undeveloped.

Verifying the Vertical Alignment

In order to define the profiles of each studied driveway, the contractor had taken elevation readings with surveying equipment at the observed break points (i.e., points at which changes in the profile were observable) along the profiles of each driveway. The project oversight panel expressed concern that the contractor may have not taken elevation readings at intervals spaced closely enough to precisely define the profiles of the driveways. As a check, the project oversight panel asked the contractor to resurvey three driveways with readings at more closely spaced intervals. The contractor actually resurveyed seven driveways at more closely spaced intervals.

Exhibit 4-10 shows one of the profiles generated from the initial or previous survey and from the checking re-survey. To illustrate how the information from the initial or previous survey can be compared with the later re-survey, the grades at the Arvest driveway were originally reported, based on surveying readings taken at points with observable changes of grade, as having a street cross slope of 1.2% and a driveway grade of 12.6%, creating a breakover angle of 13.8%. From the more detailed re-survey, shooting elevation readings at one foot intervals near the roadway edge, the street cross slope was found to be 1.15%, the driveway grade was 12.52%, and the resulting breakover grade was 13.67%.

EXHIBIT 4-10 Profile of Arvest driveway

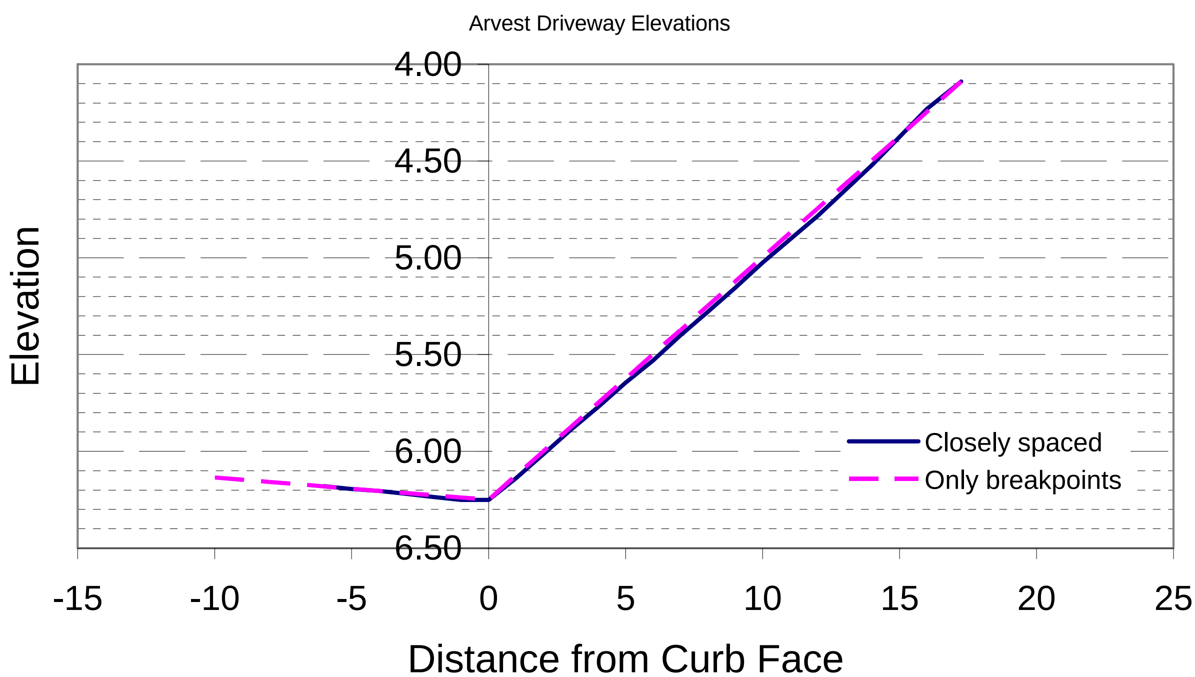
Arvest driveway, E. 61st St., Tulsa, OK

	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0 (Curb)	1	2	3	4	5	6	7	8	9	10	12	14	16	17.3
Elev. of dway 14.2' from Rt edge	6.03				6.08	6.09	6.10	6.12	6.13	6.15	6.15	6.05	5.94	5.82	5.71	5.59	5.49	5.36	5.25	5.14	5.01	4.78	4.53	4.26	4.11
Distance from curb face	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	12	14	16	17.3
Elevation of dway Rt edge	6.24				6.28	6.30	6.31	6.32	6.34	6.35	6.35	6.23	6.09	5.96	5.83	5.70	5.57	5.44	5.31	5.17	5.04	4.79	4.51	4.20	4.07
Average elevation	**6.14**				6.18	6.20	6.21	6.22	6.24	6.25	**6.25**	6.14	6.02	5.89	5.77	5.65	5.53	5.40	5.28	5.16	5.03	4.79	4.52	4.23	**4.09**
Elev. calculated from breakpoints	**6.14**	6.15	6.16	6.17	6.18	6.19	6.20	6.22	6.23	6.24	**6.25**	6.12	6.00	5.87	5.75	5.62	5.50	5.37	5.25	5.12	5.00	4.75	4.50	4.25	**4.09**
Difference between calculated and actual					0.00	0.00	0.00	0.00	-0.01	-0.01		-0.02	-0.02	-0.02	-0.02	-0.02	-0.03	-0.03	-0.03	-0.03	-0.03	-0.04	-0.02	0.02	

Values from previous measurements, based on level readings only at observed breakpoints. -1.2% 13.8% 12.6%

Breakover grade change = 13.67%

Calculated grade: ← -1.15% → | ← 12.52% →



After resurveying five of the driveways at which data had been collected, the contractor had yet to find a driveway where the breakover sag at the gutter line had been ameliorated by rounding. At two of the sites, the contractor observed rounding where a driveway ascending from the roadway gutter suddenly flattened as it met a sidewalk. At the Stonegate driveway, this rounding was determined to be 0.5 inch. At the Hollywood driveway, although rounding was visible, it was so slight that it was not detected with the surveying equipment.

At the sixth site to be surveyed, McAllister's, the survey readings identified a flat gutter pan that had the effect of flattening or rounding the sag profile by about 0.5 inch at a point a few inches in front of the curb line. A seventh site at which data had been collected, Union Plaza shopping center, was surveyed to quantify the grades that were causing the undersides of vehicles to drag on the driveway surface. From this survey, it was noted that the cross slope at the gutter pan was actually steeper downward than the cross slope of the roadway, which created a dip of slightly less than 0.5 inch, the opposite of rounding.

In general, these exhibits indicate that the profiles made from the readings of the initial survey were close to the profiles made from the follow-up checking survey. Of the seven sites at which data were collected, the checking re-surveys found that one of them had slight rounding of the sag, one of them had a dip at the sag, and the other five had no noticeable adjustment of the profile at the sag point where the street cross slope abuts the driveway grade. At one site, the survey also identified pavement rutting in the outer lane of the through roadway.

Data Collection Procedures

Prior to the field data collection, project oversight panel members had suggested that the contractor consider using contact closure switches to record speed of vehicles entering the driveway. After evaluating alternative methods, the contractor proposed patterns of contact closure switch pairs to record the speed and elapsed time between successive stations as vehicles turned right or turned left into the driveway.

To collect data, the contractor made precise measurements to set the location of pairs of contact closure switches, then taped the switches to the roadway and driveway surfaces. A pair of switches constituted a sensor. Wiring attached to the switch ends was also taped to the surface, and the wiring for each turning movement was connected to a data logger, which in turn was connected to a laptop computer loaded with a program specially designed to receive and store the readings generated in the data logger. The data logger allowed input signals from the switches to be processed and by means of knowing elapsed time over a set distance, calculated vehicle speed. A person operating the computer would key the devices to record data when a turning vehicle approached the sensors. A camcorder was aimed to include Sensors 2 and 3 in the field of view. Exhibit 4-11 displays these two patterns, one for right-turning and one for left-turning vehicles.

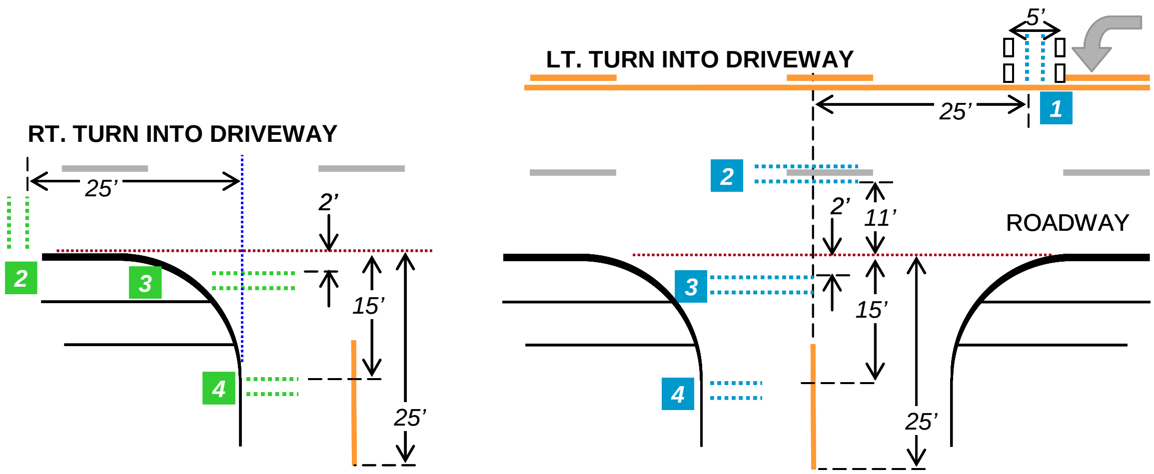


EXHIBIT 4-11 Sensor layout diagrams

To record the data from right-turning vehicles, three sensors (i.e., pairs of contact closures switches) were deployed. These pairs were named Sensors #2, #3, and #4.

Initially, the left turn data were collected with four pairs of contact closure switches, numbered #1 through #4. Due to ongoing problems with the switches, the decision was made to eliminate pair #1. This was done to eliminate the long electrical wiring required to reach these switches, the associated demand for power, and the longer signal transmission distance. It was hoped that this would improve the reliability of the remaining three left-turn switch pairs.

Note that the pairs of switches actually recorded the speed of the vector perpendicular to the orientation of the switches, which may in some cases be slightly less than the actual forward speed of the vehicle. The switches at Sensor #3 recorded the vehicle speed vector toward pedestrians on the sidewalk.

Data Collection Problems and Adjustments

At some sites, data were collected on multiple dates. The main reason for repeat visits to the site was a technical failure, either with the wiring leading to the contact closure switches or the software. Repeat visits also had to be made because of damp weather and because of vehicles damaging the contact closure switches. The manufacture of the contact closure switches stated that they were intended to be used by vehicles going straight, and the tire movement of turning vehicles could cause problems.

For the first three studies conducted, Sensor #4 was positioned 25 ft back from the roadway curb line. From observations during this data collection, it was concluded that at this distance, some drivers were beginning to react to maneuvers or traffic conflicts in the driveway throat ahead. This was affecting speeds differently at different sites. Therefore, this distance was adjusted to 15 ft back from the roadway curb edge.

At the Stonegate driveway, there were numerous marks from the scraping of vehicle undersides at the locations for Sensors 3 and 4. During the first data collection trip, some vehicles scraped the sensors. Based on this experience, in the second and third studies at the site, Sensor 3 was shifted two feet closer to the curb, so the lead switch aligned with the curb face. During the second study, Sensor 4 was shifted two feet farther into the driveway throat, so the leading switch was 17 ft from the curb face. During the third study, Sensors 2 and 4 were both shifted up (i.e., in advance) two feet, to preserve the standard spacing between sensors.

At the Union Plaza site, the slightly wider outer lane on Mingo Road caused left turn Sensor 2 to be struck by so many through vehicles that the sensor was damaged during the February study. During the repeat left turn study in March, left turn Sensor 2 was shifted two feet, so the lead switch was 15 ft from the curb face instead of the normal 13 ft.

Because the locations of some sensors were moved, adjustments were made during the analysis. These are discussed later in this report.

Achieving a More Common Entry Throat Width

To help confine those vehicles turning into the driveway to a common width at the various sites, the contractor created a driveway centerline by installing a 15 foot long strip of 4 inch wide yellow pavement marking tape. To partially compensate for variations in the radii among the different sites and for the construction of slightly irregular radii, the contractor placed the yellow pavement marking tape at the greater of either an offset distance of 13 ft from the straight edge of the driveway, or after measuring back from the face-of-curb (FC) edge a distance of 13.2 ft, an offset distance of 14.2 ft from the entry radius. These 13.2 and 14.2 ft distances were chosen to replicate the throat width available 70° into a right turn having a 20 foot radius into a 13 ft wide entry lane (see Exhibit 4-12).

The intent of the pavement marking tape was reinforced by the practice of positioning a blocking vehicle in the driveway exit lane (see Exhibit 4-13). This vehicle essentially parked in the exit lane until such time as another vehicle trying to leave the site pulled up behind the blocking vehicle. When this occurred, the blocking vehicle drove away and then quickly returned to the blocking position. This practice was followed at all sites except Union Plaza, where the volume of exiting traffic was sufficient to perform the blocking task. A small piece of white pavement marking tape was placed to help the driver of the blocking vehicle stop close to the same spot each time.

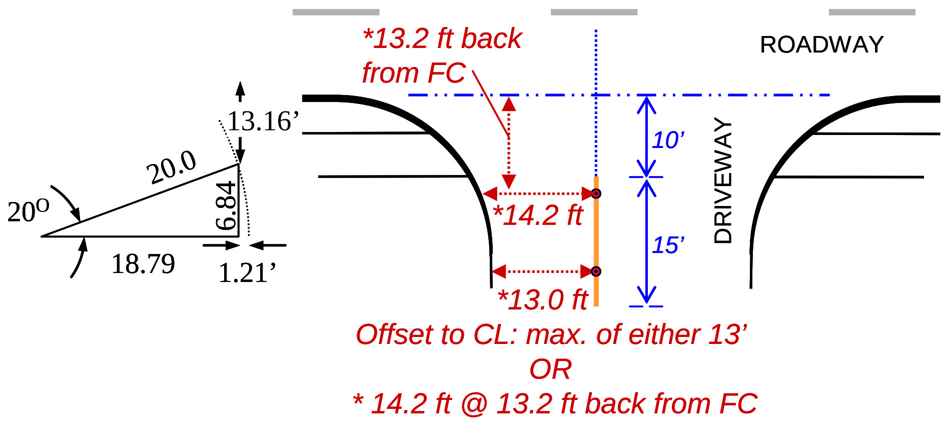


EXHIBIT 4-12 Width available 70° through a 90° right turn

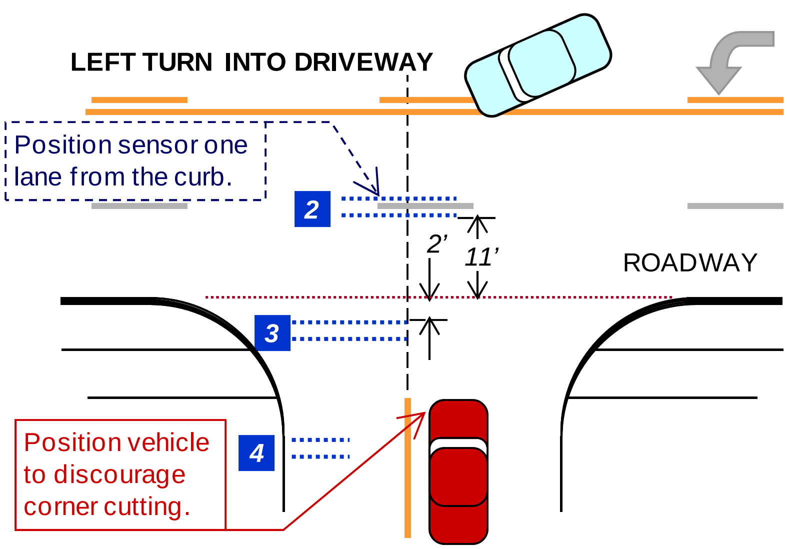


EXHIBIT 4-13 Position of blocking vehicle

Exhibit 4-14 shows two people installing a pair of sensors at a data collection site. Exhibit 4-15 shows a site with data collection in progress. Note that the computer operators were partially screened from the view of drivers with a three-sided, 30 inch high barrier on a frame weighted to remain steady in the breeze.

EXHIBIT 4-14 Installing contact closure switches

EXHIBIT 4-15 Data collection in progress

Data Reduction and Analysis

After collecting the field data, files were downloaded from the laptop computers, and the strings of data were formatted into columns in a spreadsheet. Those reducing the data meticulously examined spreadsheet entries and viewed video of the vehicles turning into the driveways.

The person reviewing the video tapes noted when right turning vehicles swung wide in the through lane and crossed the white lane line. The reviewer noted when either left or right turning vehicles crossed the yellow driveway centerline that had been installed by the researchers. Also, reviewers noted when there was interference with entering vehicle, such as a pedestrian walking in front of it. Such cases were flagged for exclusion, so the analysis would consider only unimpeded vehicles that made turns from and into the provided lane width.

Considerable effort was directed to screening the data to remove erroneous readings. Some examples follow.

Sometimes, the person operating the laptop computer collecting right turn data might incorrectly assume that an approaching vehicle was about to turn right, and set the system to record data. These through vehicles would trigger a reading on the Sensor 2 pair, but not on the following Sensors 3 and 4. In this event, Sensors 3 and 4 would have unrealistic speed readings. Screening identified these events.

Another not uncommon event was that one of the switchers in a sensor pair was stuck closed, having not rebounded from a previous tire strike. In such instances, an unrealistic speed would be generated. Again, screening identified such instances.

Another source of bad data was the result of entering vehicles turning wide. For instance, a vehicle turning left into a driveway might almost miss the sensors, but barely clip the lead switch with the inside front tire. Continuing in an arc, the front tire would miss the trailing switch. But the inward-tracking rear tire would cross both switches, triggering the hit on the trailing switch. This would generate unusually low readings, in the neighborhood of 2 mph.

A checking routine was coded in the spreadsheet to identify suspect readings. The measured elapsed time between two sensors was compared to the elapsed time calculated from the average of the speeds at two successive sensors. When this difference was relatively high, speeds and videos were checked to determine whether the readings were reasonable.

After many reviews of each file, statistical analyses were performed to compare data. For the study at the HEB driveway, the spacing between Sensors 3 and 4 was 25 ft, not the 15 ft used later on, so the recorded elapsed time was multiplied by 3/5. The values of the elapsed times at the January and July Stonegate and the March Union Plaza sites were proportionally adjusted to reflect the necessary repositioning of certain sensor pairs. Due to the problems previously mentioned, data from the following sites and dates were not used: Stonegate September, Genie September, and Hollywood September.

The data in each of the three grade groups (Flatter, Moderate, Steeper) were initially evaluated. Right turn data and left turn data were evaluated separately. Then, comparisons were made among the three grade groups.

Initial Results, Observations, and Considerations

During the course of the field data collection and the subsequent analysis, factors that could possibly affect driver behavior and the resulting speeds and elapsed travel times at specific sites were identified.

At the driveway sites, the data collectors observed that even with a 19 ft radius and a 13 ft wide entry throat, it appeared from drivers' facial expressions and driving behaviors that many turning right into the driveway felt constrained. The entering drivers' seemed concerned with the proximity of their left front bumper with the left side of the blocking vehicle in the exit lane. Some entering drivers seem to slightly halt at this point during their turn maneuver. The analogous phenomenon for left turning vehicles entering the driveway was much less pronounced.

Also, the observed directional patterns (predominately through or predominately turning) of vehicles immediately after entering the driveway, and the presence or absence of traffic conflicts in the driveway throat, may somewhat affect the speeds at Sensor 4. The following Exhibit 4-16, separately for each of the three grade groups, describes the directional traffic patterns and conflicts at each site.

Exhibit 4-17 lists the three grade groups, with the number of readings and the average speed and elapsed time values. Values are reported separately for right- and for left-turning vehicles entering the driveways.

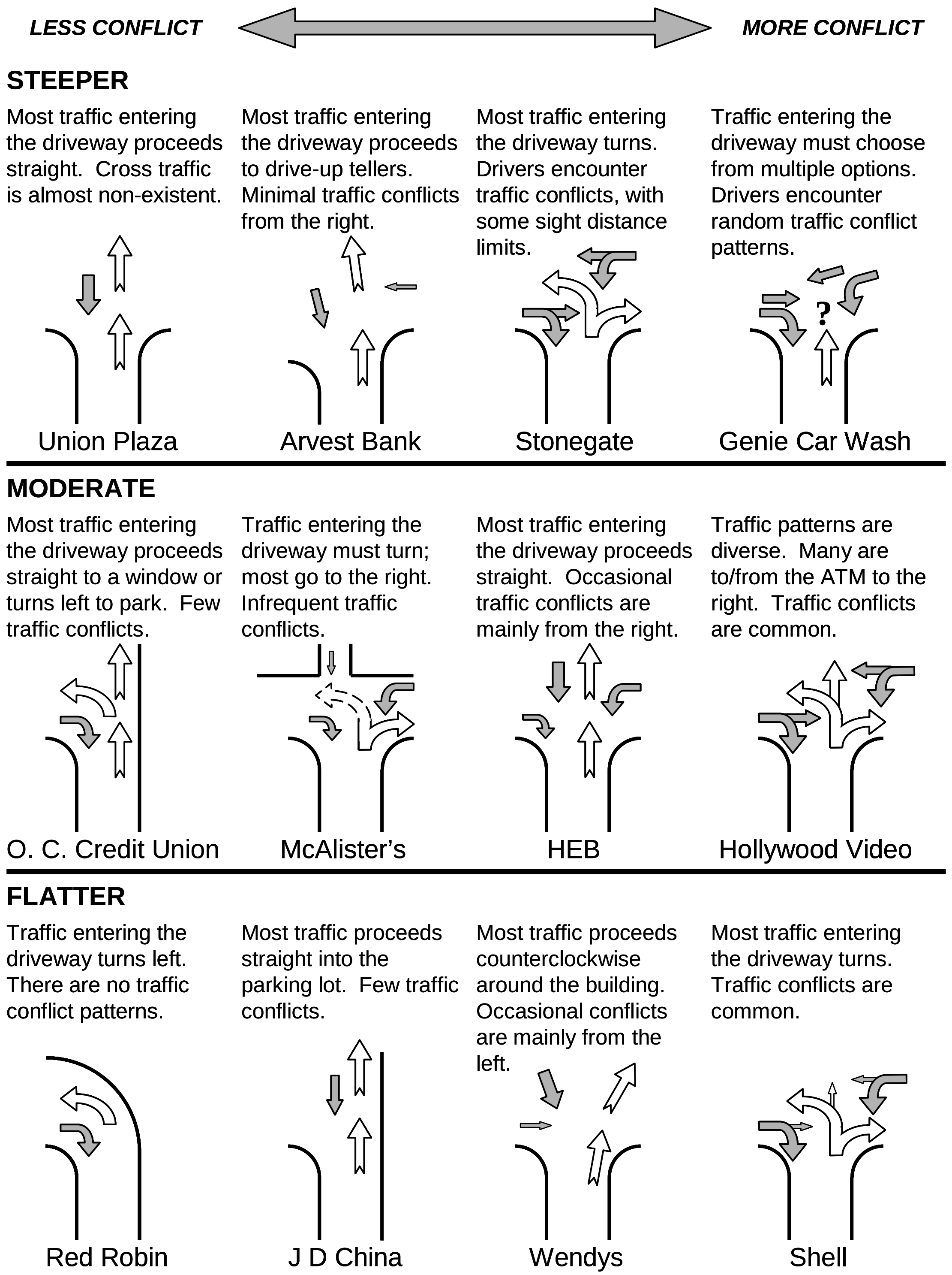


EXHIBIT 4-16 Driveway throat traffic patterns at study sites

EXHIBIT 4-17 Speed and elapsed travel time from individual sites

Site Description	Outer Lane Width (ft) See Note	Street Cross Slope	Grade Change Near Gutter Line	Dway. Grades	Throat Length (ft)	Throat Entry Traffic Pattern	Rt. Turn Entry Radius (ft)	for each site, the sample size on top, mean on bottom									
								Rt 2	Rt 3	Rt 4	Elap 2-3	Elap 3-4	Lt 2	Lt 3	Lt 4	Elap 2-3	Elap 3-4
STEEPER																	
Stonegate One - Austin Pain Assoc.	11.0	-3.1%	18.6%	15.5% 6.5' / 0.3% 6' / 13.8%	48	turn conflict	19	58	58	57	59	55	66	64	71	62	70
								15.4	4.6	5.8	1.43	1.71	10.0	7.3	6.1	1.29	1.73
Genie Car Wash	11.2	-4.2%	17.0%	12.8% 2' / 15.6%	23	turn conflict	19	78	85	78	79	78					
								14.7	5.3	5.4	1.51	1.67					
Union Plaza - Mardells	13.5	-2.6%/ -7% 1'	15.8%	13.2% 4' / 3.4% 6' / 5.3% 8'	48	thru free	13.5	83	83	83	80	81	95	112	123	88	112
								13.9	5.1	6.4	1.79	1.53	9.4	8.9	9.2	1.04	1.08
Arvest Bank	12.6	-1.2%	13.8%	12.6%	29	thru free	16						48	51	49	42	47
													9.5	9.7	8.2	1.09	1.09
							number =	219	226	218	218	214	209	227	243	192	229
MODERATE																	
Okla. Central Credit Union	11.5	-1.8%	10.5%	8.7% 10' / 12.8%	66	mixed free	18	36	40	40	40	40	77	74	69	61	74
								13.4	5.6	7.5	1.62	1.42	8.8	9.8	10.1	1.07	1.04
McAlisters, Meineke	13.0	-3.8%/ -1%	10.1%	6.4% 12' / 5.5%	64	turn free	16	86	88	84	87	88	60	67	72	72	73
								14.8	5.7	7.4	1.65	1.37	9.5	11.4	11.4	1.12	0.86
small shop. center- HEB grocery	11.0	-4.0%	10.0%	6.0% 10' / 1.1%	41	thru conflict	13	47	47	40	0	40					
								14.1	7.2	7.6	--	1.20					
Hollywood Video - Southcross Plaza	11.5	2.0%	5.1%	7.1% 6.5' / 2.2% 4.5' / 0%	29	turn conflict	17	167	164	163	166	164	162	151	179	135	170
								15.1	5.4	6.8	1.51	1.45	10.7	9.8	8.6	1.01	1.09
							number =	336	339	327	293	332	299	292	320	268	317
FLATTER																	
Wendys	13.0	-2.1%	6.5%	4.4% 11' / 1.3%	40	turn free	15.5	61	62	64	61	61	121	114	117	115	115
								13.9	5.7	6.7	1.75	1.49	11.1	10.9	10.1	0.94	0.89
J D China	11.5	-0.5%	5.2%	4.7% 20' - 2.0% 6'	43	thru free	19	19	24	24	18	23	42	42	40	39	42
								12.7	5.0	7.0	1.40	1.48	8.4	8.9	9.1	1.14	1.07
Shell gas; self storage	12.0	-2.0%	5.0%	3.0% 9' - 0.8%	52	turn conflict	19.5	77	94	80	73	81	0	65	61	0	56
								13.8	5.5	6.8	1.47	1.39	--	10.7	10.1	--	0.89
Red Robin	11.5	-2.1%	3.7%	1.6%	58	turn free	19.5	84	85	83	81	82	18	20	20	17	18
								14.8	5.5	7.9	1.41	1.34	9.2	10.5	11.1	0.99	0.90
							number =	241	265	251	233	247	181	241	238	171	231
NOTE: Outer lane width is measured from the lane line to the entry-radius tangent							Total number of all =	796	830	796	744	793	689	760	801	631	777

From observations in the field during data collection and from an analysis of the data, the following remarks are offered about factors that may have affected drivers' speeds as they entered the driveways.

Steeper Sites

The higher level of throat traffic conflict may have contributed to lower speeds at Sensor 4 at Stonegate and at Genie. The lower level of conflict may have contributed to higher Sensor 4 speeds at

Union Plaza. Also at Union Plaza, the dip in the cross section at the gutter line may have caused drivers to proceed at lower speeds at Sensor 3 than they would have if the cross slope had remained constant.

Moderate Sites

At McAlister's, the flattened gutter pan may have caused left-turning drivers to proceed at higher speeds at Sensor 3 than they would have if the cross slope had remained constant. The data also suggest that the higher level of traffic conflict in the Hollywood throat caused speeds at both right- and left-turn Sensor 4 to be lower.

Flatter Sites

The pavement rutting in the outside lane at J. D. China may have caused left-turning drivers to proceed at lower speeds at Sensors 2 and 3 than they otherwise would have. The only Flatter site which seems to have been affected by the absence or presence of throat congestion was Red Robin, which had little congestion and faster speeds at Sensor 4.

Shell was the only site at which it was thought that occasional traffic congestion in the outer through lane may have affected driveway flow. From time to time, vehicles that turned right into the next driveway downstream from the subject driveway were observed to begin decelerating in advance of the subject driveway.

CHAPTER 5
Research Findings

This chapter presents the results from the research that had been conducted with the following three objectives.

1. Determine the crest and sag grade changes at which a static vehicle drags the underside.
2. Determine what actual driveway profiles cause the undersides of vehicles to drag.
3. Assess the effects of angle changes (roadway cross slope – driveway grade) at the roadway-driveway interface and driveway grades on the speed and elapsed time of vehicles turning left and turning right into a driveway.

5.1 DRIVEWAY GRADES AND MEASURED VEHICLE GROUND CLEARANCE

The underside of a vehicle can drag or hangup in two ways. On a sharp vertical crest, the pavement surface can come in contact with the underside of a vehicle between the front and rear axles. At a sharp vertical sag, the road surface may drag or scrape the underside of a vehicle either to the front of the front axle or to the rear of the rear axle.

After making measurements to define the underside profiles of selected vehicles, the angles at which these profiles would drag or scrape the pavement surface were calculated. Exhibit 5-1 shows the calculated grades at which underside dragging would occur. Note that these measurements represent a static condition. The measurements do not account for the effects of additional static loading on the vehicle (such as weight of the passengers or cargo), or for the vertical displacement which may result from the dynamic forces on the vehicle in motion. In actual driving conditions, one would expect underside dragging to occur at grade changes that were somewhat less than those listed.

5.2 DRIVEWAY GRADES AND SIGNS OF INADEQUATE GROUND CLEARANCE

Visible scrape marks on the surface that result from the dragging of vehicle undersides can be clear indicators that the profile geometry of an existing driveway is too abrupt. After identifying driveways with scrape marks and measuring the crest and or sag breakover angles near scrape marks, the breakover angles on each driveway were calculated. For those driveways with a crest breakovers close to a sag breakovers, the contractor was not able to determine with certainty if the scrape marks were the result of the crest or the sag profile.

Scrapes on driveways with crest breakovers of 9% and 10.5% were observed. However, in both cases the crest was close to a sag, and the investigator could not determine which situation was causing the undersides of vehicles to drag on the driveway surface. A number of crest profiles with breakovers ranging from 10.9% to 11.4% were observed. From this, it was concluded that although it is possible that the undersides of vehicles were dragging at lesser breakovers, there was more evidence to support a maximum allowable crest profile breakover of 10%.

For driveways with sag profiles, the search uncovered a few faint scrapes on a driveway with a breakover of 8.6% . Starting with breakover angles of 10%, more sag profiles with scrapes were noted. It was concluded that although it is possible that the undersides of vehicles were dragging at lesser breakovers, there was more evidence to support a maximum allowable sag profile breakover of 9%.

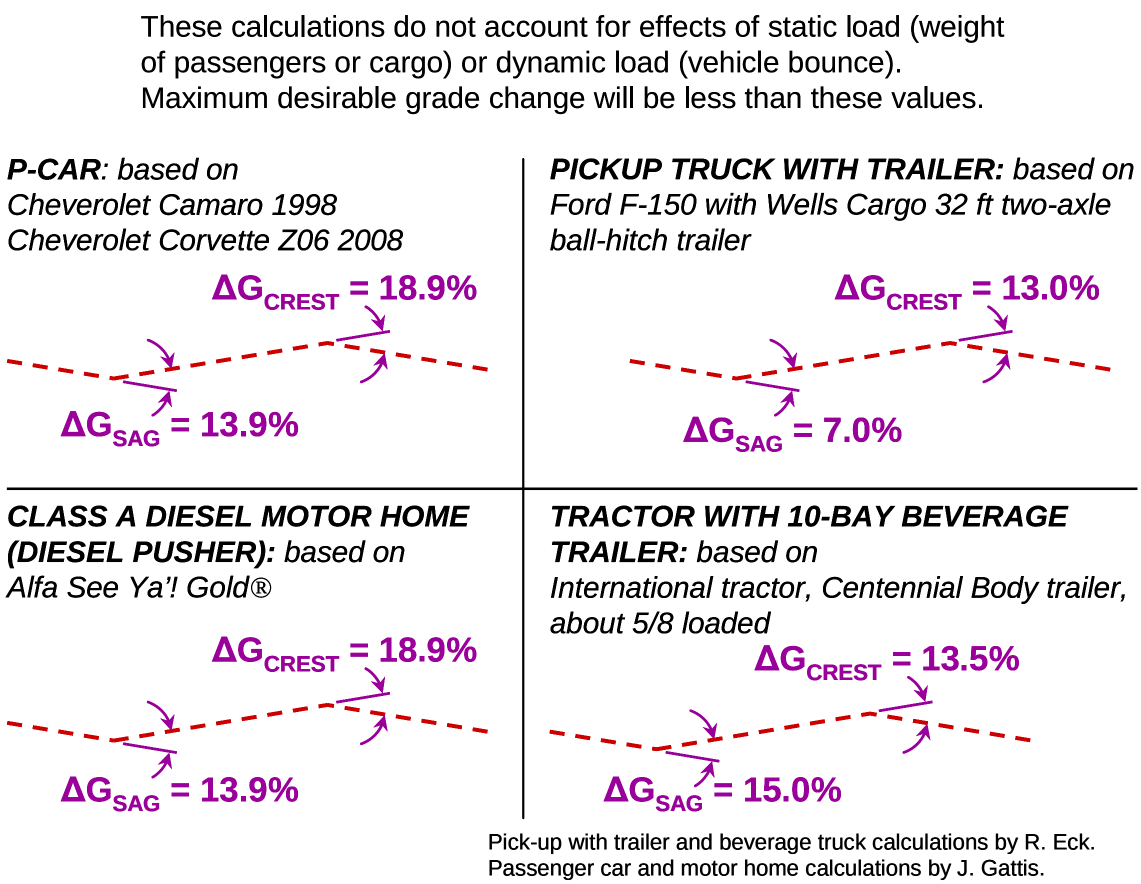


EXHIBIT 5-1 Computed profile changes to induce vehicle underside dragging

5.3 DRIVEWAY GRADES AND SPEEDS OF ENTERING VEHICLES

The majority of the research effort was focused on examining the effects of driveway vertical profiles on the speeds and elapsed travel times of vehicles turning right and turning left into driveways. This section presents the outcomes of these studies.

Examining Effects of Other Variables

Before proceeding to analyze the relationships between driveway vertical alignment and speeds of vehicles turning into the driveway, relationships involving the outer lane width and the radius were examined to determine if they were also affecting speeds.

Examination of Right Turn Speed and Outer Lane Width

The average speeds of right-turning vehicles at Sensors 2 and 3 were plotted against the widths of the outside through lane. An examination of Exhibit 5-2 does not indicate that lane width influenced right turn entry speeds.

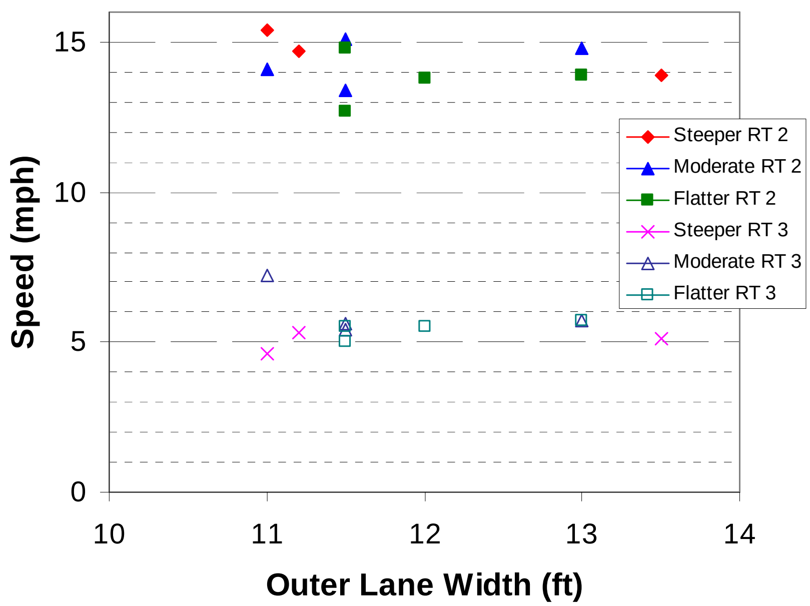


EXHIBIT 5-2 Outer lane width and right turn speeds

Examination of Right Turn Speed and Radius

Exhibit 5-3 displays, for each site, the right turn average speed vector at Sensor 3. These values are sorted across by grade group, and vertically by radius. From the data in this table, one does not find an increase in right turn radius associated with an increase in the average speed of the vehicles turning right into the driveways. However, the average speeds of the three Steeper sites do appear to be generally less than those in the other groups.

EXHIBIT 5-3 Right turn speed vectors at Sensor 3 and different right turn radii

	Flatter			Moderate grade, flatter breakover			Moderate			Steeper		
Radius range	Site	R	Avg. V mph	Site	R	Avg. V mph	Site	R	Avg. V mph	Site	R	Avg. V mph
19.5' to 18'	Shell	19.5'	5.5									
	Red Robin	19.5'	5.5									
										Stonegate	19'	4.6
	J D China	19'	5.0							Genie	19'	5.3
							Ok. Central	18'	5.6			
17' to 15'				Hollywood	17'	5.4						
							McAlister's	16'	5.7			
	Wendy's	15.5'	5.7									
13.5' to 13'										Union Plz	13.5'	5.1
							HEB	13'	7.2			

Examination of Speed and Throat Length

Exhibit 5-4 shows average speeds at Sensor 4 of both right- and left-turning vehicles entering the driveways, plotted against the driveway throat length. Left-turn speeds were higher than right-turn speeds. The plot suggests that speeds at Sensor 4 tended to be slightly higher at sites with longer throats.

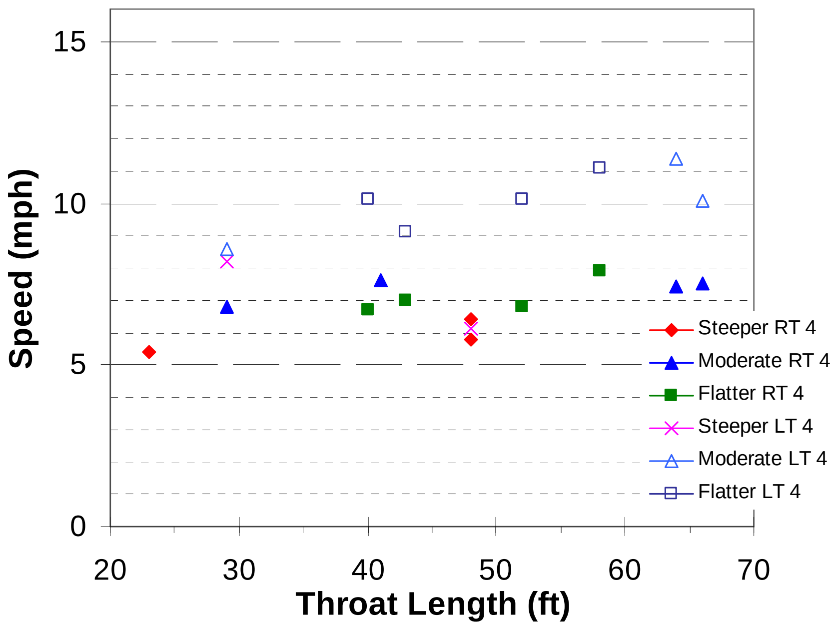


EXHIBIT 5-4 Throat length and speeds at Sensor 4

Speed and Elapsed Travel Time Statistical Comparisons

The separate analyses of right-turning and left-turning vehicles entering the driveways produced the following values in Exhibits 5-5 through 5-14. Tests for statistically significant differences were performed with $\alpha = 0.1$.

Speed at Right Turn Sensor 2

At right-turn Sensor 2, on the main roadway just before the driveway, the average speeds of vehicles turning into the driveway were similar. Average speed was lowest at the Flatter sites and highest at the Moderate sites. The difference between the means of the Flatter and Moderate was statistically significantly different, at $p < 0.01$.

Over most of the range, speeds at the Flatter sites were less than those at the other two groups. The presence of a larger standard deviation value indicates a greater dispersion of the speeds among the sites in that group.

Interestingly, the posted speed limit at all four Steeper sites was 40 mph. Half of the other sites were posted at 45 mph, and half at 40 mph. This difference does not seem to have caused speeds at the Steeper sites to be less than those at the other sites.

	Flatter	Moderate	Steeper
Sample size N	241	336	219
Maximum speed	22.8	19.8	20.7
90th percentile speed	17.1	17.1	17.1
75th percentile speed	15.9	15.9	16.1
Average speed	14.1	14.7	14.5
25th percentile speed	12.6	13.5	13.4
10th percentile speed	10.5	12.2	12.0
Minimum speed	5.1	7.9	5.3
Standard deviation	2.9	2.0	2.1

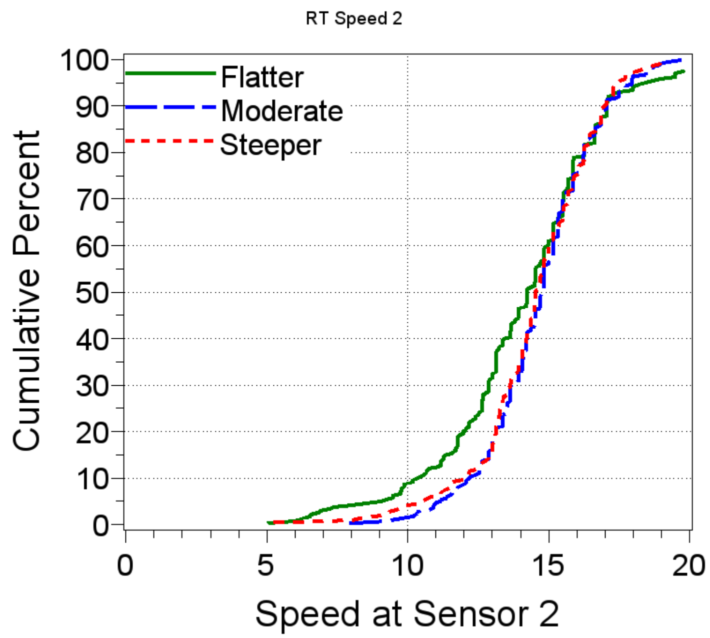


EXHIBIT 5-5 Right Sensor 2 data

Elapsed Travel Time Between Right Turn Sensors 2 and 3

Between right-turn Sensor 2 and Sensor 3, the Flatter sites' mean elapsed travel time was significantly less than the mean of the Steeper sites, with $p = 0.073$. The magnitude of the greatest difference between pairs of means was less than 0.1 second. Over most of the distributions, the values for the Flatter sites were less than those at the Steeper sites.

	Flatter	Moderate	Steeper
Sample size N	233	293	218
Maximum	2.94	3.59	2.66
90th percentile	1.96	1.92	2.00
75th percentile	1.72	1.70	1.80
Average	1.52	1.56	1.59
25th percentile	1.25	1.38	1.35
10th percentile	1.10	1.24	1.19
Minimum	0.73	0.69	0.76
Standard deviation	0.38	0.32	0.34

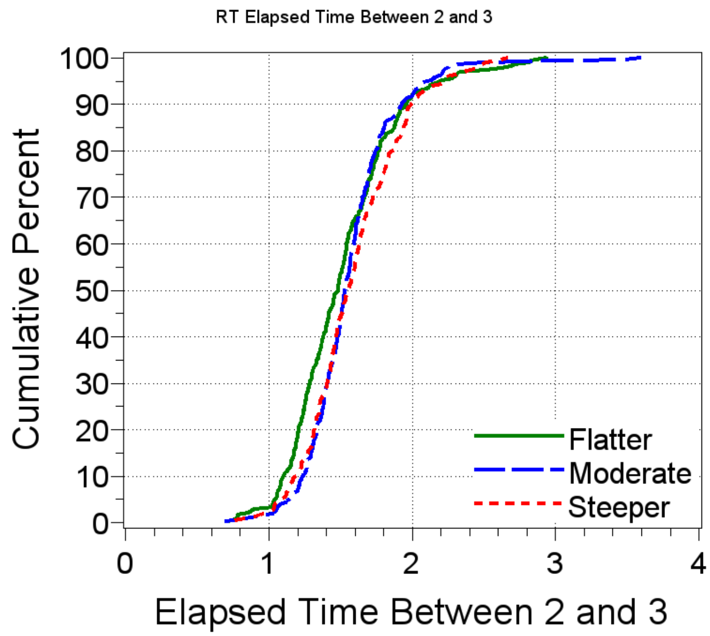


EXHIBIT 5-6 Right 2 to 3 elapsed time

Speed at Right Turn Sensor 3

All of the average speed vectors at right-turn Sensor 3, measured just after a vehicle crossed the threshold of the driveway, were statistically significantly different from each other, with p-values less than 0.01. Steeper sites had the slowest average speed, and Moderate sites the highest, but the size of this difference was 0.7 mph. Throughout the most of the ranges of the speeds, the Steeper speeds were lower than speeds at the other two groups.

Note that this measurement is the speed vector perpendicular to the through street and the sidewalk, and is likely to be on the magnitude of 25% to 40% less than the actual forward speed of the vehicle at this point.

	Flatter	Moderate	Steeper
Sample size N	265	339	226
Maximum speed	11.3	9.8	9.9
90th percentile speed	6.6	7.3	6.1
75th percentile speed	5.9	6.4	5.6
Average speed	5.5	5.8	5.1
25th percentile speed	4.8	5.0	4.4
10th percentile speed	4.3	4.4	3.9
Minimum speed	3.1	3.3	3.0
Standard deviation	1.0	1.2	1.0

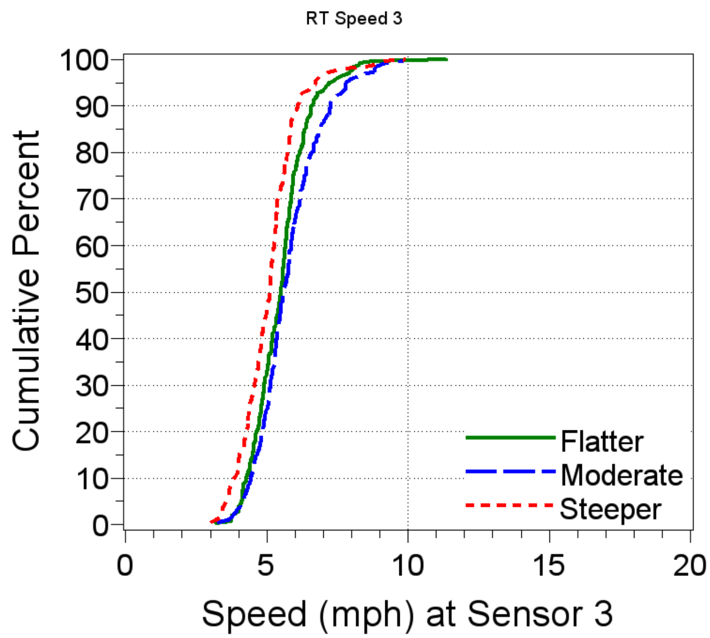


EXHIBIT 5-7 Right Sensor 3 data

Elapsed Travel Time Between Right Turn Sensors 3 and 4

The average elapsed times of vehicles traveling between Sensors 3 and 4 were similar for the Flatter and the Moderate groups. The average of the Steeper sites was significantly longer than the other two averages, with $p < 0.01$.

Over much of the range, Steeper elapsed times were about ¼ sec longer than those in the other two groups.

	Flatter	Moderate	Steeper
Sample size N	247	332	214
Maximum	3.29	2.35	2.95
90th percentile	1.76	1.73	2.09
75th percentile	1.58	1.56	1.84
Average	1.41	1.39	1.63
25th percentile	1.23	1.20	1.37
10th percentile	1.10	1.08	1.26
Minimum	0.71	0.74	0.98
Standard deviation	0.31	0.26	0.34

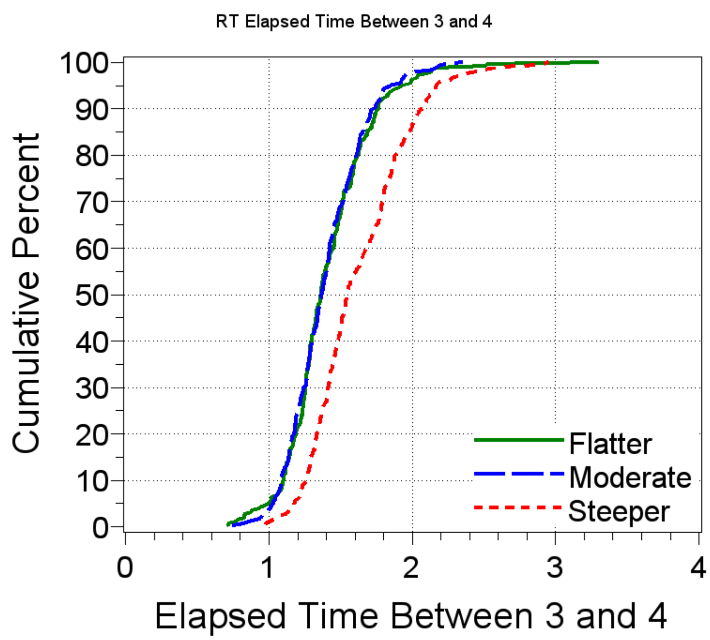


EXHIBIT 5-8 Right 3 to 4 elapsed time

Speed at Right Turn Sensor 4

At Sensor 4, speeds on the Steeper driveways were about 1 mph under those on the Flatter and Moderate driveways. Speeds on the Flatter and the Moderate driveways were similar. The average Steeper speed was statistically significantly lower than the other two average speeds ($p < 0.01$).

	Flatter	Moderate	Steeper
Sample size N	251	327	218
Maximum speed	14.1	13.0	9.0
90th percentile speed	9.0	8.9	7.8
75th percentile speed	8.1	8.1	6.8
Average speed	7.2	7.2	5.9
25th percentile speed	6.1	6.2	5.0
10th percentile speed	5.3	5.3	4.2
Minimum speed	3.1	3.5	3.3
Standard deviation	1.6	1.5	1.3

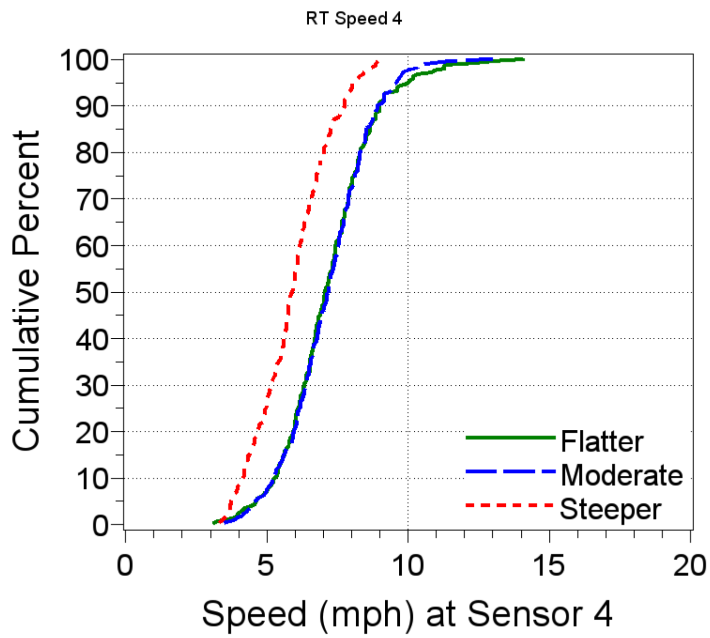


EXHIBIT 5-9 Right Sensor 4 data

Speed at Left Turn Sensor 2

Over much of the range of data recorded at Sensor 2, one lane width in advance of the driveway threshold, the Steeper site speeds were almost 1 mph less than the Flatter site speeds. Most of the Moderate speeds fell between the Flatter and the Steeper speeds.

The Steeper average speed was significantly lower than both the Flatter and the Moderate average speed ($p < 0.01$).

Vehicles turning left into the driveways often crossed Sensor 2 at a slight skew. The readings reflect the speed vector perpendicular to the sidewalk. The actual forward speeds were probably 5% to 10% greater than the recorded speeds.

	Flatter	Moderate	Steeper
Sample size N	181	299	209
Maximum speed	18.7	16.2	17.9
90th percentile speed	12.5	12.3	11.7
75th percentile speed	11.7	11.3	10.6
Average speed	10.3	10.0	9.6
25th percentile speed	8.7	8.9	8.6
10th percentile speed	7.5	7.5	7.3
Minimum speed	4.9	3.2	3.3
Standard deviation	2.0	2.0	2.0

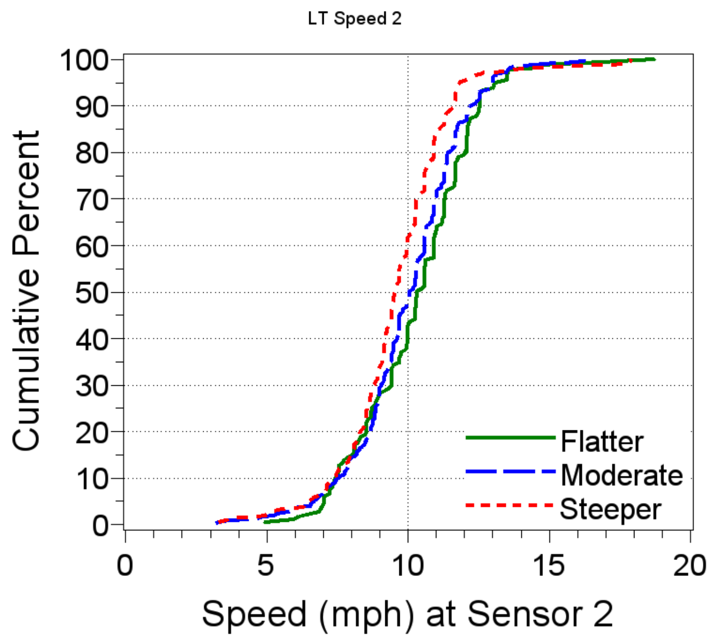


EXHIBIT 5-10 Left Sensor 2 data

Elapsed Travel Time Between Left Turn Sensors 2 and 3

In general, elapsed times between Sensors 2 and 3 at the Flatter sites were the shortest, while the elapsed times at the Steeper sites were the longest.

From paired comparisons, all of the average elapsed times were significantly different from each other ($p < 0.03$), with Flatter having the shortest times and Steeper having the longest times.

	Flatter	Moderate	Steeper
Sample size N	171	268	192
Maximum	1.88	2.84	2.56
90th percentile	1.25	1.37	1.46
75th percentile	1.08	1.13	1.28
Average	0.99	1.05	1.09
25th percentile	0.86	0.87	0.96
10th percentile	0.78	0.79	0.84
Minimum	0.50	0.62	0.56
Standard deviation	0.20	0.32	0.30

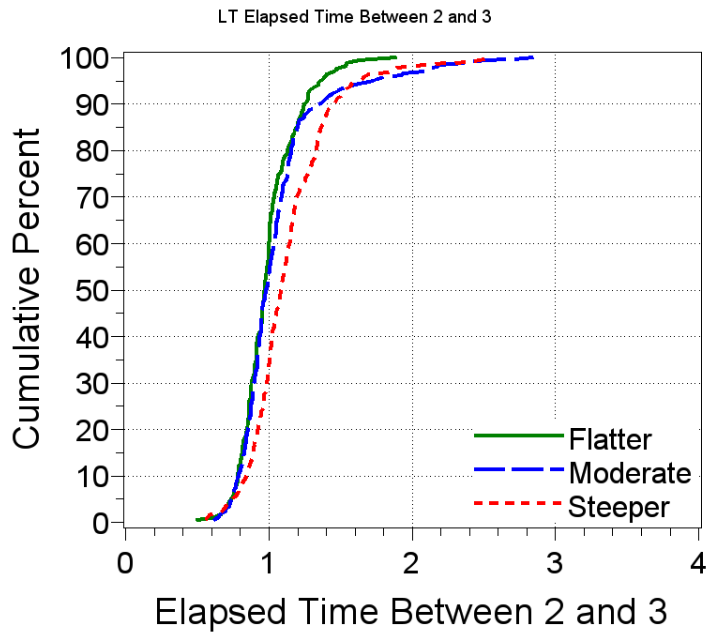


EXHIBIT 5-11 Left 2 to 3 elapsed time

Speed at Left Turn Sensor 3

Over much of the range of data recorded at Sensor 3, just past the driveway threshold, Flatter site speeds were about 1 to 2 mph faster than Steeper site speeds. Moderate site speeds were slightly less than those at the Flatter sites.

Average speeds at the Steeper sites were significantly less than those at the other two site groups ($p < 0.01$). Speeds at the Steeper sites were more dispersed, indicated by the larger value of the standard deviation.

	Flatter	Moderate	Steeper
Sample size N	241	292	227
Maximum speed	**21.0**	16.1	18.7
90th percentile speed	13.0	13.0	12.1
75th percentile speed	11.7	11.5	10.3
Average speed	10.4	10.2	8.7
25th percentile speed	9.1	8.8	6.8
10th percentile speed	7.8	7.7	5.4
Minimum speed	5.6	3.1	3.1
Standard deviation	2.1	2.0	2.7

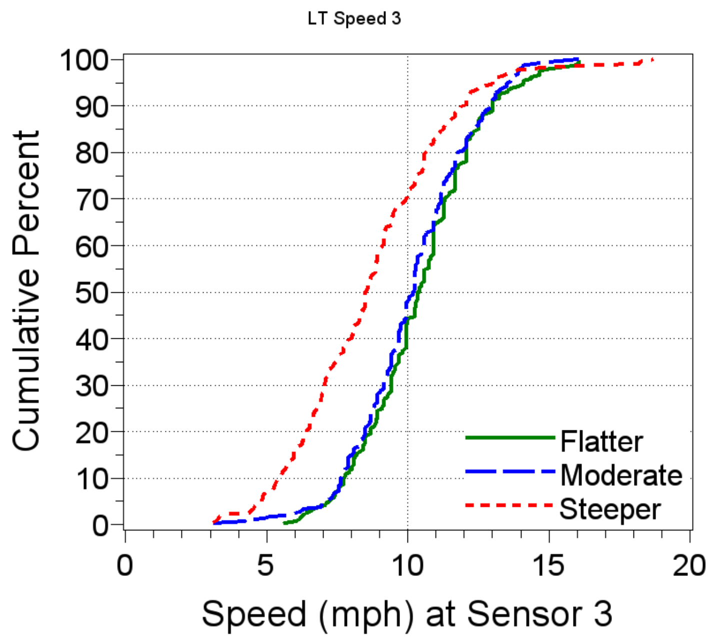


EXHIBIT 5-12 Left Sensor 3 data

Elapsed Travel Time Between Left Turn Sensors 3 and 4

Between Sensor pairs 3 and 4, the average Steeper site elapsed time was over 0.3 sec longer than the Flatter site average. The elapsed travel times at the Moderate sites were slightly longer than those at the Flatter sites. There was more dispersion of elapsed time at the Steeper sites, indicated by the larger value of the standard deviation.

From paired comparisons, each of the average elapsed times was significantly different from the other two ($p < 0.01$), with Flatter having the shortest times and Steeper having the longest times.

	Flatter	Moderate	Steeper
Sample size N	231	317	229
Maximum	1.74	2.68	2.90
90th percentile	1.20	1.51	1.96
75th percentile	1.03	1.11	1.56
Average	0.93	1.02	1.28
25th percentile	0.79	0.81	0.89
10th percentile	0.72	0.70	0.77
Minimum	0.43	0.57	0.48
Standard deviation	0.21	0.36	0.48

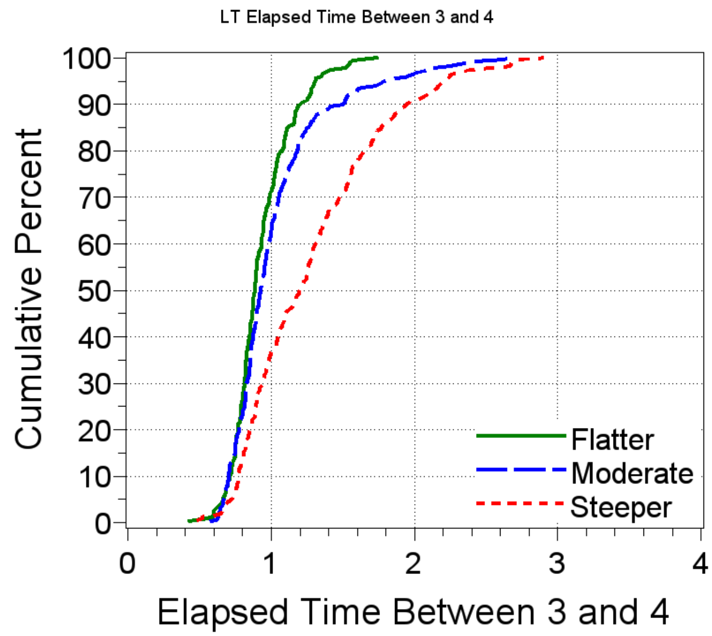


EXHIBIT 5-13 Left 3 to 4 elapsed time

Speed at Left Turn Sensor 4

At left turn Sensor 4, between the 25th percentile and the 75th percentile readings, the speeds at the Steeper sites were about 2 mph lower than those at the Flatter sites.

The average of the speeds at the Steeper sites was significantly less than that at the other Flatter or Moderate sites ($p < 0.01$).

	Flatter	Moderate	Steeper
Sample size N	238	320	243
Maximum speed	21.0	18.4	18.4
90th percentile speed	13.0	13.0	11.7
75th percentile speed	11.4	11.1	9.7
Average speed	10.0	9.5	8.1
25th percentile speed	8.5	7.9	6.2
10th percentile speed	7.1	6.4	4.9
Minimum speed	5.2	3.7	3.0
Standard deviation	2.3	2.5	2.8

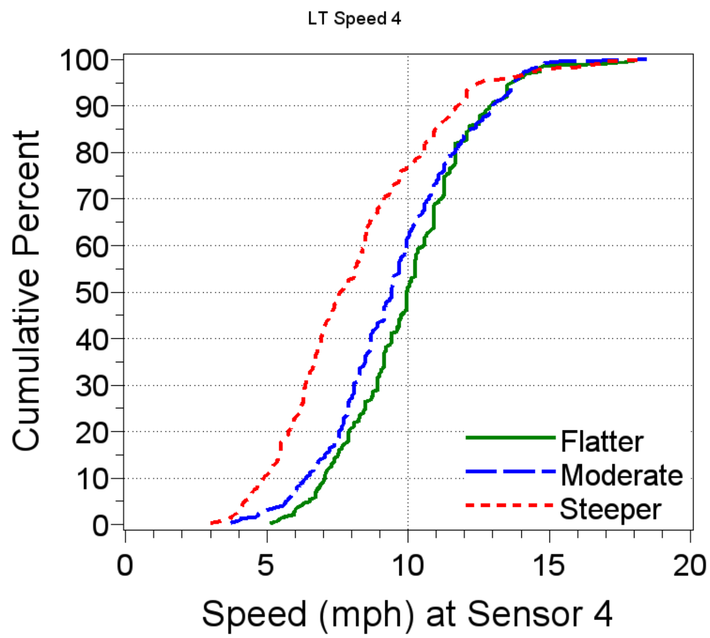


EXHIBIT 5-14 Left Sensor 4 data

5.4 SUMMARY OF FINDINGS

These findings are based on measurements of the ground clearances of five vehicle types, measurements made at 31 driveways with visible scrapes from the undersides of vehicles, and the measured speeds and elapsed travel times for over 1500 vehicles observed turning right or left into a driveway. The speed and elapsed time studies were conducted at commercial driveways on non-fringe suburban arterial multilane roadways with posted speeds of 40 and 45 mph. All of the roadways had either a raised median or a TWLTL. These data were collected at driveways with right turn entry radii ranging from 13 to 19.5 ft, and an entry lane width of about 13 feet.

Very few vehicles about to enter a driveway exceeded 20 mph at the locations at which speeds were measured. After crossing the driveway threshold, average speeds for vehicles turning left into the driveway were around 10 mph. Vehicles that had turned right into the driveways were slightly slower, with average speeds around 7 mph.

From observations of drivers' behavior, it was not uncommon for drivers turning right into a driveway with these dimensions to feel slightly constrained. Sometimes, the observed speeds and elapsed times for the Flatter and the Moderate grade groups were similar, while the Steeper group had slightly slower speeds and longer elapsed times. There were more differences of speed and elapsed travel time among the three grade groups (Flatter, Moderate, Steeper) with drivers turning left into the driveway than turning right. While a number of the differences among the three grade groups were statistically significant, the magnitudes of the differences were not large.

From examining the data from the one site with a moderate grade but a flatter breakover angle (due to a superelevated roadway cross section), it was unclear to what extent drivers react merely to the driveway grade looming in front of them and to what extent they perceive the actual breakover. From one site, there was some evidence that pavement rutting in the outside lane may slow the travel of a vehicle turning left into a driveway. Entry speeds were slightly higher at driveways with longer entry throats.

Some of the driveways were surveyed to obtain elevations readings at closely-spaced intervals. This was done to determine if during construction, the driveway breakover angle had been rounded to somewhat smooth the transition from roadway cross slope to driveway grade. Of the seven sites at which data were collected, these surveys found that one of them had slight rounding of the sag, one of them had a dip at the sag, and the other five had no noticeable adjustment of the profile at the sag point where the street cross slope meets the driveway grade.

Right Turn Entry Into Driveways

Exhibit 5-15 shows that for the vehicles observed turning right into the driveways studied, speed vectors and elapsed time between Sensors 2 and 3 for varied slightly among the Flatter, Moderate, and Steeper grade groups. The differences were more pronounced between Sensors 3 and 4, with the Steeper group having a lower average speed and a longer average time.

The overall average elapsed travel times from Sensors 2 to 4 were about the same for the Flatter and Moderate sites. The Steeper site average elapsed time was about ¼ sec longer than that for the other two groups.

EXHIBIT 5-15 Average values for vehicles turning right into driveways

	Speed 2 (mph)	Elapsed time 2 to 3 (sec)	Speed 3 (mph)	Elapsed time 3 to 4 (sec)	Speed 4 (mph)	Sum of Elapsed time (sec)
Steeper	14.5	1.59	5.1	1.63	5.9	3.22
Moderate	14.7	1.56	5.8	1.39	7.2	2.95
Flatter	14.1	1.52	5.5	1.41	7.2	2.93

Left Turn Entry Into Driveways

Exhibit 5-16 shows that for the left turning vehicles observed in this study, average speeds for the Flatter and Moderate sites within the driveway (Sensors 3 and 4) were about 1.5 to 2.5 mph higher than those for the Steeper sites.

From Sensor 2 to Sensor 4, there was less than 1/6 sec difference between the average elapsed travel time for the Flatter group and for the Moderate group. The average of the elapsed travel time for the Steeper group was over 1/3 sec slower than the average for the other two groups.

EXHIBIT 5-16 Average values for vehicles turning left into driveways

	Speed 2 (mph)	Elapsed time 2 to 3 (sec)	Speed 3 (mph)	Elapsed time 3 to 4 (sec)	Speed 4 (mph)	Sum of Elapsed time (sec)
Steeper	9.6	1.13	8.7	1.28	8.1	2.41
Moderate	10.0	1.05	10.2	1.02	9.5	2.07
Flatter	10.3	0.99	10.5	0.93	10.0	1.92

Application

One way in which these findings can be applied is to compare the effects of a steeper driveway on the following three users: a motorist turning into a driveway, a pedestrian on the sidewalk, about to cross the driveway; and a through motorist approaching the driveway. Through vehicles traveling at the posted speed of 45 mph are traveling 66 ft/s. A faster pedestrian might be walking at a speed of 6 ft/s.

- Assume that due to having a steeper driveway, a vehicle turning right into the driveway requires an additional total elapsed travel time of 0.25 sec. This translates to the following.

  - for a pedestrian, about 1.5 ft of walking distance, or not more than a single step

  - for a motor vehicle turning into a driveway at 17 mph or 24.9 ft/s, a distance of 6 ft, or less than half of a typical car length

  - for a through motor vehicle at 45 mph behind a motor vehicle that has slowed to turn into a driveway, about 16 ft, or the length of a car

- Assume that due to having a steeper driveway, a vehicle turning left into the driveway requires an additional total elapsed travel time of 0.4 sec. This translates to the following.

  - for a pedestrian, about 2-½ ft of walking distance, less than two steps

  - for a motor vehicle turning left into a driveway at 12 mph or 17.6 ft/s, a distance of about 7 ft, slightly less than half of a typical car length

  - for an oncoming motor vehicle at 45 mph approaching a motor vehicle that is turning left into a driveway, about 26 ft, or about one-and-a-half car lengths

Of these differences in time and distance, and the increased conflicts among the two motorists and the pedestrian due to the effects of the steeper driveway, the one with the greatest potential for a collision would seem to be the one involving the turning vehicle and the through vehicle.

CHAPTER 6
Summary and Recommendations

This report describes the work performed and the recommendations developed during the conduct of this research project. It reviews driveway-related literature and agency practices, identifies geometric elements and performance measures, lists research needs, and describes the procedures and findings of the research conducted. Key findings follow.

Sixteen state transportation agencies and one local agency responded to a national survey. Most states reported that their standards (or practices) differed according to development density, land use type, or roadway characteristics. Most had an access management code or policy. For commercial and residential driveways, there was a slight preference for the curved entry-edge transition over the flared or tapered treatment as the design of first choice. None allowed a direct connection with an unpaved driveway; a plurality of respondents required paving the driveway all the way to the right-of-way line. Reported problematic issues included those related to driveway grades, and to the entry-edge transition.

Over 90 documents that pertained to some aspect of driveway design were reviewed. Most documents focused on motor vehicles. Several more recent publications, however, also covered pedestrian and Americans with Disabilities Act (ADA) requirements. Topics covered in the literature review included user characteristics, safety, driveway entry geometry, driveway angle, setbacks for on-site storage, right turn lanes, vertical alignment, coordinating bus stops and driveways, and access location and spacing.

A number of component driveway design factors were identified as they relate to the range of users (including bicyclists, motorists, and pedestrians), vehicles, the public roadway, and the surrounding environment. About 30 of these factors are usually beyond the control of the driveway designer, while the designer often has some influence over more than 60 listed factors. Fourteen key geometric (or geometry-related) elements were identified, and performance measures were developed for each. Based on the adequacy of current information and the perceived importance of each element, the need and desirability for further research was also discussed.

Based on the information described above, the contractor suggested that the project oversight panel consider the following five topics for research.

1. Analysis of Driveway Influenced Crashes
2. Visual and Tactile Cues to Identify the Pedestrian Route Across the Driveway
3. Effects of Driveway Plan-Geometry on Turning Vehicles
4. Driveway Triangular Islands
5. Driveway Vertical Alignment Guidelines

The Interim Report presented work plans for the topics suggested for further research. It included reasons for conducting each research, proposed methodology, factors that may affect success, and preliminary cost estimates. After deliberation, the project oversight panel directed the contractor to focus the research effort on topics related to the design of the vertical alignment of driveways.

The Task 6A research work was comprised of the following three studies.

1. Determine the crest and sag grade changes at which a static vehicle drags the underside. This was accomplished by measuring the ground clearance dimensions of five vehicles: Chevrolet Camaro, Chevrolet Corvette, Ford F-150 pickup with a trailer, Class A diesel motor home, and a tractor with a 10-bay beverage trailer.
2. Determine what actual driveway profiles cause the undersides of vehicles to drag. This was accomplished by measuring and analyzing the profiles of 31 driveways which had visible scrape marks on the pavement surface.
3. Assess the effects of breakover angle changes (roadway cross slope – driveway grade) at roadway-driveway interface, and driveway grades. The vast majority of the effort was devoted to this objective, which was accomplished by measuring and analyzing the speeds and elapsed times of vehicles turning right and turning left in to commercial driveways on urban multilane roadways with flatter, moderate, or steeper grades. All of the driveways were on roadways with either a raised median or a TWLTL, and with a posted speed of 40 or 45 mph.

6.1 RECOMMENDATIONS

The contractor measured the geometry of the undersides of selected vehicle, actual driveways at which scrape marks from vehicle underside dragging were observed, and speeds and elapsed travel times of vehicles turning into driveways. Based on a combination of the three parts of this research, the following guidelines (Exhibit 6-1) are offered for driveways of the type studied, those serving small- and medium-sized commercial tracts located on non-fringe suburban multilane arterial roadways. These guidelines are not necessarily applicable to driveways in rural or in urban core, central business district environments.

The contractor also prepared a separate document, a guide for the geometric design of driveways. This guide focused on the more typical driveways, not those driveways that look like streets.

Recommendation	Rationale
• Limit the maximum driveway grade to +8% (except where a lesser grade is required, such as when crossing a sidewalk), and the maximum breakover without a vertical curve between the roadway cross slope and an uphill driveway grade to 9%.	For vehicles observed turning right into the driveways, there was little difference between the speeds and travel times at Flatter and at Moderate sites. For vehicles observed turning left into the driveways, those at the Moderate sites were slightly slower than those at the Flatter sites.
• Limit the driveway profile maximum grade change without a vertical curve for a crest to 10%.	From measurements of 31 driveways with scrape marks, underside dragging became a problem at a crest of about 11%.
• Limit the driveway profile maximum grade change without a vertical curve for a sag to 9%.	From measurements of 31 driveways with scrape marks, underside dragging became a problem at a sag of about 10%.
Observation	**Rationale**
• A minimum entry radius of 20 ft with an entry lane of 12 or 13 feet is not excessive. The width can narrow by means of a taper after the radius return.	During the field data collection, conducted at driveways with radii between 13 to 19.5 ft, it appeared from drivers' facial expressions and driving behaviors that many turning right into the driveway felt constrained. The entering drivers' seemed concerned with the proximity of their left front bumper with the left side of the blocking vehicle in the exit lane. Some entering drivers seem to slightly halt at this point during their turn maneuver. Since entry radius was not specifically studied, more study of this element is needed.

NOTE: These recommendations were based in part on the observed operational characteristics of over 1500 vehicles turning right and turning left into commercial driveways having radii ranging from 13 to 19.5 ft. The driveways were on multilane arterial roadways with posted speeds of 40 and 45 mph. For driveways on roadways with higher speeds, driveways designed in the manner of a street or road, or driveways serving low-boy or other low trailers, lesser grades and breakovers may be appropriate.

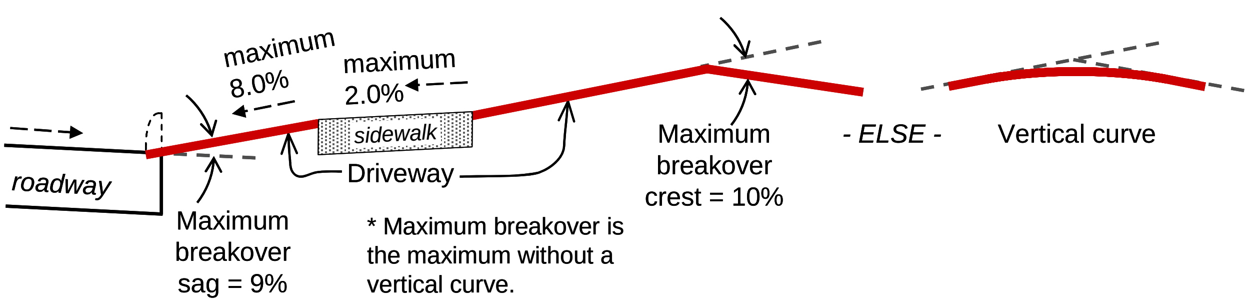


EXHIBIT 6-1 Recommended maximum grades for a driveway designed for P-vehicle

6.2 RECOMMENDED REVISIONS TO THE GREEN BOOK

In closing, the following (Exhibit 6-2) revisions to Chapters 1, 2, 3, 4, 5, 6, 7, and 9 of the 2004 AASHTO *A Policy on Geometric Design of Highways and Streets* (Green Book) (*3*) are offered for consideration. Chapters 8 and 10 are excluded, since they address freeways and interchanges.

In addition, material from this report can be incorporated into either Chapter 5 (in a format parallel to that of the Special-Purpose Roads section) or Chapter 9.

EXHIBIT 6-2 Suggested changes to the AASHTO Green Book

Location and current text		Recommendation
Chp. 2 p. 15-45		Recommend adding to "Design Vehicles" a discussion of vehicle ground clearance, along with dimensions.
Chp 3 p. 110	A driver on an urban street confronted by innumerable potential conflicts with parked vehicles, driveways, and cross streets is also likely to be more alert than the same driver on a limited-access facility where such conditions should be almost nonexistent. {INSERT}	After the sentence, add: However, the driver on the urban street trying to monitor the additional conflicts is also faced with a greater mental workload, and there is no guarantee that the driver will be able to more quickly detect an immediate threat from among the many potential sources of conflict.
Chp 3 p. 265		Recommend adding a discussion of maximum allowable change of grade (i.e, breakover) to avoid the vehicle underside dragging or hanging up.
Chp 3 p. 283	The crossroad or street intersections and the location of driveways are dominant controls.	Be more explicit, revise to read: The horizontal and vertical positions of intersecting roadways and driveways are dominant controls.
Chp 4 p. 349	The regulation and design of driveways is intimately linked with the available right-of-way and the land use and zoning control of the adjacent property. On new facilities, the needed right-of- way can be obtained to provide the desired degree of driveway regulation and control. To prohibit undesirable access conditions on existing facilities, either additional right-of-way can be acquired or agreements can be made with property owners to improve existing conditions. Often the desired degree of driveway control must be effected through the use of police powers	

	by requiring permits for all new driveways and adjustment of existing ***ones*** that do not conform to established regulations. The objective of driveway regulations is to preserve efficiency and promote operational efficiency by prescribing desirable spacing and proper layout of driveways. The attainment of these objectives is dependent upon the type and extent of legislative authority granted to the highway agency. Many states and local municipalities have developed design policies for driveways and formed separate units to issue permits for new, or for changes in existing, driveway connections to main highways. For further information on the regulation and design of driveways, refer to ~~***Guidelines for Driveway Design and Location (22).***~~ {INSERT}	Recommend replacing the reference to the 1985 ITE document at the end of this paragraph with a reference to the TRB *Access Management Manual*. Recommend inserting the following narrative as a new paragraph to follow the existing paragraph shown: "To the extent possible, driveway designers should attempt to address a range of objectives, including (1) not degrading the safety and efficiency of operation on the intersecting roadway, (2) providing safe and reasonable access and egress, (3) providing sight distance and safety for sidewalk users, (4) incorporating ADA requirements related to pedestrians with disabilities, (5) accommodating bicycle lanes or paths when they are present, and (6) maintaining public transportation stops, when present. The *Guide for the Geometric Design of Driveways*, developed as part of NCHRP Project 15-35, provides guidelines for the design of the various driveway elements (ref)."
Chp 4 p. 349	Driveway regulations generally control right-of-way encroachment, driveway location, driveway design, sight distance, drainage, use of curbs, parking, setback, lighting, and signing. Some of the principles of intersection design can also be applied directly to driveways. An important feature of driveway design is the elimination of large graded or paved areas adjacent to the traveled way upon which drivers can enter and leave the facility at will. Another feature is the provision of adequate driveway widths, throat dimensions, and proper layout to accommodate the ***anticipated*** types ***and volumes*** of vehicles patronizing the roadside establishment. {INSERT}	Recommend inserting the words "anticipated" and "and volumes". Recommend inserting the following sentences at the end of the existing paragraph shown: "Vertical alignment elements are also important in driveway design and should allow vehicles to conveniently and expeditiously enter and exit the driveway. Profiles should avoid the possibility of a vehicle dragging or hanging up on the driveway. The vertical alignment of the driveway must reflect limitations on the sidewalk cross slope to accommodate pedestrians and pedestrians with disabilities. In addition, profiles need to allow for adequate drainage."
Chp 5 p. 398	Some of the principles of intersection design apply directly to driveways. In particular, driveways should have well-defined locations. Large graded or paved areas adjacent to the traveled way, which allow drivers to enter or leave the street randomly, should be ~~***discouraged***~~ ***prohibited***.	Recommend changing "discouraged" to "prohibited"

Chp 5 p. 398	Driveway returns should not be less than ***1 m [3 ft]*** in radius. Flared driveways are preferred because they are distinct from intersection delineations, can properly handle turning movements, and can minimize problems for persons with disabilities. {INSERT 1} {INSERT 2} Further guidance on the design of sidewalk-driveway interfaces can be found in the AASHTO Guide for the Planning, Design, and Operation of Pedestrian Facilities (5).	From the project report, a 3 ft. radius will seldom be adequate, and a blanket statement supporting flared driveways was not substantiated. (1) Consider inserting guidance here related to entry geometry and other design elements. (2) Recommend inserting the following reference: "The *Guide for the Geometric Design of Driveways*, developed as part of NCHRP Project 15-35, provides guidelines to use in the design of the various driveway elements, including grade, entry geometry, width, channelization, and cross slope (ref)."
Chp 6 p. 436	**Driveways** Driveways should be regulated as to width of entrance, placement with respect to property lines and intersecting streets, angle of entrance, vertical alignment, and number of entrances to a single property. ADA guidelines should be considered in the design of driveways (6, 7). {INSERT} Further guidance on the design of sidewalk-driveway interfaces can be found in the AASHTO *Guide for the Planning, Design, and Operation of Pedestrian Facilities* (9).	Recommend inserting the following narrative in the existing paragraph where shown: "The *Guide for the Geometric Design of Driveways*, developed as part of NCHRP Project 15-35, provides guidelines to use in the design of the various driveway elements, including grade, entry geometry, width, channelization, and cross slope (ref)."
Chp 9 p. 730	{INSERT} The regulation and design of driveways are intimately linked with the type of road and zoning of the roadside. On new highways, right-of-way can be obtained to provide the desired degree of driveway regulation and control. In some cases, additional right-of-way can be acquired with the reconstruction of an existing highway or agreements can be made to improve existing undesirable access conditions. Often the desired degree of driveway control should be effected through the use of police powers to require permits for all new driveways, through adjustments of existing driveways, or through access-management regulations.	Recommend inserting the following narrative as a new paragraph to precede the existing paragraph shown: "Every driveway connection creates an intersection, which may create conflicts with bicyclists, pedestrians, and motor vehicles. An objective of driveway design is to seek a balance that minimizes the actual conflicts and accommodates the demands for travel and access. The *Guide for the Geometric Design of Driveways*, developed as part of NCHRP Project 15-35, provides guidelines to use in the design of the various driveway elements, including grade, entry geometry, width, channelization, and cross slope (ref)."
Chp 9 p. 730 to 731	The main objectives of driveway regulation are to provide desirable spacing of driveways and to ensure that a proper internal layout is being proposed.	

	Achieving these objectives depends on the type and extent of legislative authority granted the highway agency. Many states and cities have developed policies for driveways and have separate units to handle the design details that are incidental to checking requests and issuing permits for new driveways or requested changes to existing driveway connections. Major controls and design features are discussed in other reference sources (19, 20, ***21***).	Recommend replacing reference document #21 – the Institute of Transportation Engineers *Guidelines for Driveway Design and Location* – with the NCHRP 15-35 report, *Guide for the Geometric Design of Driveways*.

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APPENDIX A-1

Survey of Current Practices

This appendix presents the questions to and responses from the 16 state and one local transportation agencies that returned completed survey forms.

1. Does your agency have different driveway geometric design standards or practices for different types or classes of roadways or situations, such as rural or urban, residential or commercial, etc.?

1. RESPONSES All but one indicated "yes," they did have different standards or practices. The reported bases for the differentiation can be grouped into these three categories.

Land development density: Rural or Urban

Land-use type: Non-residential or Residential

Roadway characteristics: Arterial or Non-Arterial, High-speed or Low-speed, Curb or Shoulder, Number of through roadway lanes

2. Does your agency have and normally enforce an access management policy or code to regulate the number, location, and spacing of driveways?

2. RESPONSES NO = 1 YES = 14 Sometimes = 2

3a. Where a sidewalk and a driveway cross, does your agency normally require/construct the sidewalk and the driveway surfaces to meet at the same elevation (no vertical drop off)?

3a. RESPONSES NO = 0 YES = 15 Sometimes = 2

Comments:
* Generally, with a radial return style driveway, an ADA ramp is used. Otherwise the sidewalk and driveway surface would be at the same level.

3b. Where a sidewalk and a driveway cross, does your agency normally require/install truncated-dome detectable warnings?

3b. RESPONSES NO = 9 YES = 2 Sometimes = 5

Comments:
* Wherever a ramp is used, or if the driveway is 24 ft wide.
* For major commercial driveways. Not for minor commercial or residential.
* If the driveway has curb, curb ramps and truncated domes would be required.

4. Where a driveway crosses either a sidewalk or a bike facility, does your agency normally require/construct any **other geometric design features** (i.e., not traffic signs or signals) for cyclists, elderly or disabled pedestrians, or public transit users?

4. RESPONSES NO = 15 YES = 2

Comments: Consider using a triangular island for pedestrian refuge in a high-volume driveway.

5. Driveways to shopping centers or other major generators are sometimes constructed so that they have the appearance of a public street, such as the driveway having normal full-height curb. If a driveway is built like a public street, does this fact by itself cause your agency **to apply a different set of criteria or policies** to the driveway -- other than the obvious difference of looking more like a public street than a typical driveway?

5. RESPONSES NO = 8 YES = 5 Sometimes = 4

6. Given a four-legged intersection, consisting of three public street approaches and one driveway approach. If the three public street approaches are signalized, **what type of traffic control** is normally installed on the fourth approach, the driveway? ***(Exclude from consideration** private driveways serving a large traffic generator, such as a shopping center.)*

6. RESPONSES

	Residential	Non-residential
driveway approach is signalized, served with a separate phase	0	1
driveway approach is signalized, moves at the same time as the opposite approach	6	7
signalized, phasing can vary	1	6
stop sign is installed on the driveway approach	1	0
no traffic control is installed on the driveway approach	2	1
other - please describe	4	2

Observation: For the situation described, the responses showed a general trend of overall trend for signalizing either a residential or a non-residential approach. The practice of signalizing a non-residential approach is highly prevalent.

7. Does your agency have any criteria (such as in a table) to establish a relationship **between driveway entry radius or entry angle/flare/taper dimensions and other features** such as driveway width, mainline roadway speed, etc.?

7. RESPONSES NO = 5 YES = 12

Observation: In the documents from some of the agencies that had responded “yes”, the person reviewing the documents was unable to find content that established a specific relationship between entry radius and width or speed.

See related exhibits in the appendix.

8. Does your agency have criteria (such as in a table) to determine when a driveway is allowed to **have more than 2 lanes**?

8. RESPONSES NO = 12 YES = 5

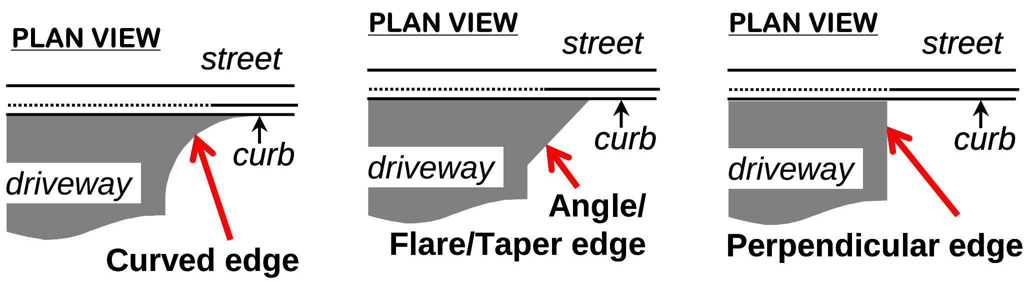
Observation: In the documents from some of the agencies that had responded “yes”, the person reviewing the documents was unable to find specific criteria; instead, there were ranges of widths to choose from.

See example in the appendix.

9. What edge-transition shape(s) does your agency normally use **at the driveway-roadway interface**? *(For this question, consider only the plan view, and do not consider various alternatives for curb-height.)*

9. RESPONSES For Commercial and for Residential situations, more respondents preferred the Curved entry, with the Angle/Flare/Taper shape coming in a close second. The Perpendicular shape was a distant third.

1 # 2 # 3



10. Are any **design vehicle** (such as P, SU) **characteristics** such as turning radius explicitly incorporated into your agency’s typical driveway geometric design(s)?

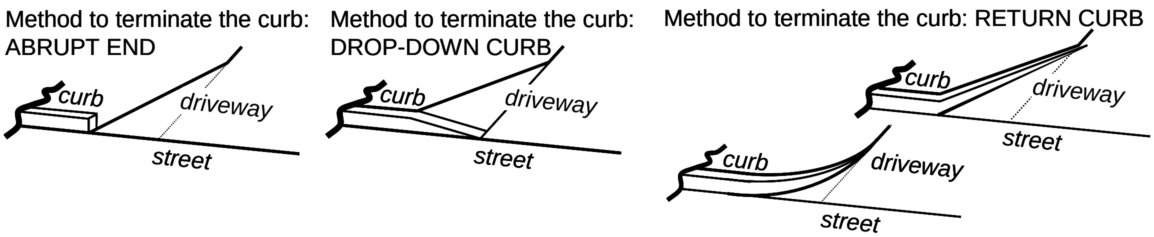
10. RESPONSES NO =9 YES = 8

Observation: Specifically-named vehicles included P for residential, SU for minor, and WB-50 or WB-62 for major roadways.

See related exhibits in the appendix.

11. What curb-termination treatments does your agency normally use **at the driveway-roadway interface**?

11. RESPONSES For both Commercial and Non-commercial locations, the returned-curb was preferred slightly-more than the drop-down curb. A majority responded that they prohibit an abrupt end treatment.



12a. When an unpaved (gravel, dirt) driveway connects to your agency's roadways, what is your agency's usual requirement for **paving the part of the driveway** close to your roadway?

12a. RESPONSES None of the respondents reported not having a requirement for this. Even though no single predominant method was evident from the reported practices, most respondents were satisfied with whatever their particular practice is.

Typically, pave the driveway from the roadway edge back to the ROW line	7
Pave the driveway back from the roadway edge for a set distance	6
Other	6

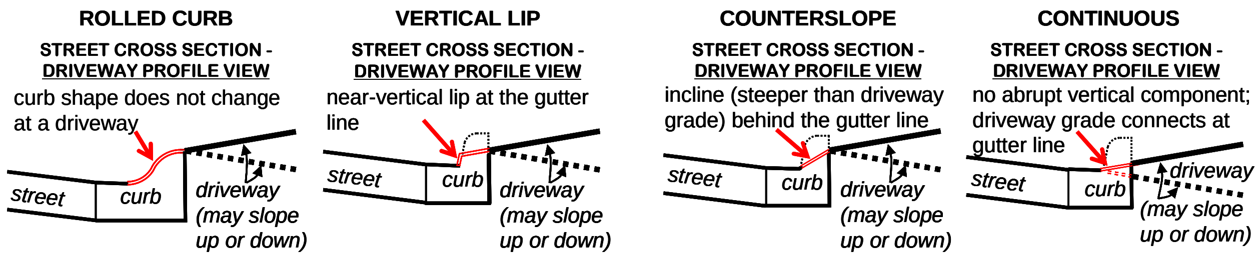
12b. **Is your currently required distance usually adequate** to prevent mud, gravel, or other driveway debris from being tracked onto the roadway, sidewalk, and or bike lane?

12b. RESPONSE

No - our currently required distance often is not adequate	2
Yes - our currently required distance is usually adequate	14

13. What vertical treatment(s) does your agency normally use **at the driveway-roadway interface**?

13. RESPONSES Responses were fairly evenly divided between favoring a curb with a slight discontinuity (Vertical Lip and Counterslope) and favoring no discontinuity (Continuous). However, opposition to a slight discontinuity (Vertical Lip and Counterslope) was much more pronounced than opposition to no discontinuity (Continuous).

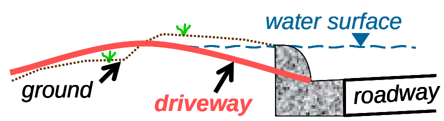


Observation: Attitudes toward the Rolled curb can be characterized as a few tolerating it and more prohibiting it.

		Rolled	Vertical Lip	Counterslope	Continuous
for Commercial	preferred =	1	4	3	6
	allowed =	1	4	3	6
	prohibited =	7	4	4	0
for Non-commercial, or Residential	preferred =	1	2	4	5
	allowed =	2	3	4	3
	prohibited =	5	4	2	1
for Residential only (excluding other Non-commercial)	preferred =	0	0	0	1
	allowed =	1	1	1	0
	prohibited =	0	0	0	0

14. For roadways that have curbs, does your agency normally set the roadway, curb, and driveway elevations so that any gutter flow that is not deeper than the normal curb height is confined, and will not drain back onto private property at driveway openings? (see the accompanying drawing)

elev. of roadway, curb, and driveway are set so the gutter flow is confined, does not run back onto private property

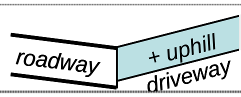
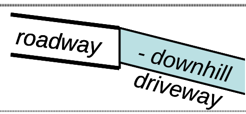


14. RESPONSES NO = 2 YES = 12 Sometimes = 3

15. Does your agency find that any particular driveway geometric treatment (such as entry shape) is more economical/expensive to construct, or more difficult/easier to construct?

15. RESPONSES NO = 14 YES = 3 (two thought that Flared costs less; the third response was related to pipe cover)

16. Agencies were asked to list their criteria for certain design elements. The following table displays an analysis of the combined values reported by the agencies.

↓ The rows below list various geometric design criteria for driveways.	Normally, use this in most situations			Commercial			Residential		
	Smallest reported	Average	Largest reported	Smallest reported	Average	Largest reported	Smallest reported	Average	Largest reported
Width for 2-way: normal maximum (ft.)	24	34	40	35	40	46	12	23	30
Width for 2-way: normal minimum (ft.)	12	24	35	12	22	30	8	12	15
Grade: maximum (+) uphill from road allowed 	2.6	9.7	15	5	7.5	10	6	11	15
Grade: maximum (-) downhill from road allowed 	-5	-9.4	-15	-5	-7.8	-10	-6	-11.0	-15
For 2-way drive, Minimum Angle with the roadway allowed (90^O is right-angle)	60	68	90	60	69	75	60	70	90
For 1-way drive, Minimum Angle with the roadway allowed (90^O is right-angle)	45	64	90	45	68	90	45	66	90
Entry-shape plan-view dimensions									
if curved radius, maximum R (ft.) =	20	41	75	40	50	70	10	23	35
if curved radius, minimum R (ft.) =	3	16	25	15	21	30	3	11	15
if Angle/Taper, max. dimensions (ft.) =									
if Angle/Taper, min. dimensions (ft.) =									
Minimum Sight Distance Required									
We base req'd Sight Dist on speed, and …									
use Green Book Stopping Sight Dist.		2			0			0	
use Green Book Intersection Sight Dist.		3			1			1	
use both.		7			2			2	
Other - please explain or attach description		0			0			0	

17. Does your agency have explicit warrants, maximum change-of-grade allowed, or design criteria for **driveway vertical curves**?

17. RESPONSES NO = 7 YES = 8

See related exhibits in the appendix.

18. **What factors does your agency consider** when evaluating whether a driveway operates well or poorly?

18. RESPONSES SUMMARIZED

General, could apply to all users	
Comfort, mobility	2
Crashes, observed conflicts, safety	5
Cross slope, grade, profile	5
Sight distance	5
Motorist specific	
Access management aspects	5
Capacity	1
Queuing – none on the highway	1
Radius and/or width	3
Speed change	1
Other-user specific	
Accommodate various modes, accessible for disabled peds.	3

19. If your or another agency you know of has **conducted any studies** that produced insight into or solutions to driveway geometric design-related issues, please briefly tell us what was studied and how to obtain the findings, or provide a contact - name, email or phone.

19. RESPONSES DO NOT KNOW OF ANY = 15 Documents cited:

Guidelines for Accessible Public Rights of Way

Recommended Design Guidelines for the Vertical Alignments of Driveways

20. If you are aware of any **designs that have successfully addressed**/solved driveway geometric design-related problems, please describe or provide information about the design (e.g., a copy of the design that solved the problem, or provide a contact - name, email or phone - with whom we can discuss the design.)

20. RESPONSES DO NOT KNOW OF ANY = 13

21. If you know of any local transportation agencies that have developed successful policies or designs for issues with or aspects of driveway geometric design, please provide the contact information.

21. RESPONSE 1

22. In the past 5 years, has your agency **received comments or criticism** about its driveway design practices from outside of the agency?

22. RESPONSES NO = 9 YES = 6 (see following table)

Those categories that were mentioned more often are listed.

pedestrian path: abrupt elevation or grade changes;

vehicle path: abrupt elevation or grade change;

grade;

absence of right-turn lane;

presence of triangular island (a.k.a. pork chop) in the driveway, to prohibit certain left-turn movements;

presence of median in the street, to prohibit some or all left-turns drainage

Most of the reported comments or complaints were made by drivers of motorized vehicles.

A table of responses is on a following page.

22. The following table shows the number of responses in each category.

	Column headings indicate the group that has the problem ➡ Complaint categories are in rows below ⬇	B Bicyclists	D Drivers of motorized vehicles	P Pedestrians	Q Ped's. using mobility aids (e.g., wheelchairs)	R Ped's. with other disabilities	T Public transport (transit, taxi) users
	Sight distance - for each column to the right, those listed in the column header..						
1	… trying to see other users		2	1			
2	… having adequate advance visibility/conspicuity of the driveway		11	1			
	For the path used by pedestrians (perpendicular to the driveway):						
3	abrupt elevation or grade change			2	2	1	
4	grade		1		1		
5	cross slope			2	2		
	For the path used by drivers (along the driveway):						
6	abrupt elevation or grade change		3				
7	grade		3				
8	Vertical curvature	1	2				
9	cross slope						
	Driveway access:						
10	**absence** of right-turn lane		3				
11	**presence** of right-turn lane		1	1			
12	presence of triangular island (a.k.a. pork chop) **in the driveway**, to prohibit certain left-turn movements		4		1		
13	presence of triangular island in the **street median area**, to prohibit certain left-turn movements		3				
14	presence of median **in the street**, to prohibit some or all left-turns		5				
	Driveway:						
15	curb treatment: use of full-height curb, fade-out curb, dustpan, etc.		1				
16	entry shape (e.g. radius, flare/taper, straight, etc.)		2				
17	entry shape dimensions						
18	number of lanes		1				
19	**absence** of raised or depressed median (in the driveway itself)						
20	**presence** of raised or depressed median (in the driveway itself)		1				
21	width		2				
22	connection depth (throat length)		1				
23	horizontal curvature		1				
24	intersection angle with sidewalk						
25	intersection angle with street		1				
26	pavement surface condition		3				
27	Drainage	1					
28	Otherwise inadequate (if possible, please briefly explain)						

23. What, if any, geometric-related driveway design practices or elements cause problems for your agency?

23. RESPONSES NONE = 9 comment = 8

Observation: Although no general trend appeared, these elements were mentioned more than once.

Driveway grade	4
Driveway width	2
Drainage	2

24. What, if any, driveway geometric design elements in your standards does your agency think are most in need of revision?

24. RESPONSES NONE = 11 comment = 5

Observation: Although no general trend appeared, three of the respondents did mention that radius standards need to be reconsidered.

25. What, if any, driveway geometric design-related issues are most in need of research?

25. RESPONSES NONE = 8 comment = 7

Observation: Although no general trend appeared, the following research topics were mentioned more than once.

effects of shape (radius, width, lip) on vehicle entry:	3
change of grade:	3

spacing:

APPENDIX A-2

Survey of Current Practices: Agency Design Documents

The survey form sent to transportation agencies included a request for copies of their standards and guidelines related to the geometric design of driveways. Most of the responding agencies furnished either electronically attached files or addresses of websites that contained their documents. From these documents, research team members gleaned the following examples.

VARIETY OF TERMS

In the course of examining the documents received from transportation agencies, the following terms were noted.

- alternate terms for driveway:
  entrances, turnouts

- alternate terms for the space between the curb and the sidewalk:
  buffer strip, grass plot, green strip, tree lawn, utility strip

- alternate terms for realigning a sidewalk near a driveway, usually to a position that is further from the roadway: jogged, walkaround

- alternate term for vertical lip:
  reveal

- terms for position of the sidewalk relative to the curb:
  "attached" (adjacent to the curb) or "detached" (set back or separated from the curb)

- terms to distinguish between two basic median categories:
  "non-restrictive"(a median or painted centerline which does not provide a physical barrier between center traffic turning lanes or traffic lanes traveling in opposite directions; includes continuous center turn lanes and undivided highways),
  or
  "restrictive median" (physically separates vehicles traveling in opposite directions and restricts the movement of traffic across the median; such as a concrete barrier, a raised curb island guard rail, or a grassed or swaled median)

STANDARD DESIGNS AND GUIDELINES OF INTEREST

The manuals and standard drawings that were submitted by the transportation agencies were reviewed to identify and collect two types of examples:

1. examples that, for a given component, show one of the many alternative design practices now in use;
2. examples that address issues that were not found in many of the documents.

The following exhibits and text include examples from both of these categories. Note that the graphical presentation styles vary greatly among the agencies. Some of the graphical methods can be more quickly and more easily understood than other methods.

Example Design Guidelines: General Dimensions

The exhibits in this section use categories nested in tables to call for certain widths, angles, or radii.

1. The design standards in this table show an entering driveway radius that differs from the exiting radius.

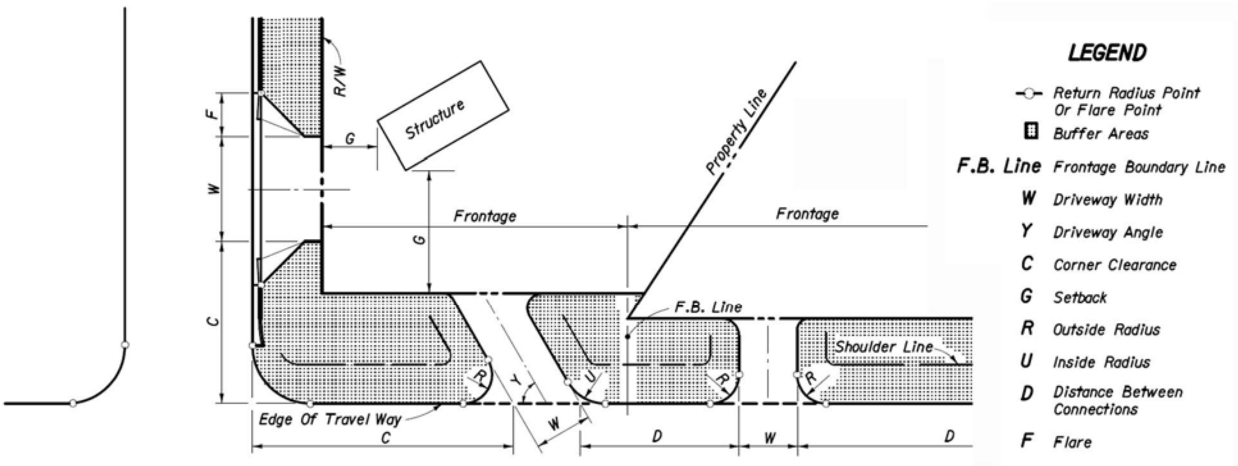
TABLE 7: RESIDENTIAL DRIVEWAY						
Design Features		Curbed Roadway		Uncurbed Roadway		
		Standard	Range	Standard	Range	
Intersecting Angle	A	90°	80 to 100°	90°	80 to 100°	
Driveway Width	B	12 ft	10 to 20 ft	12 ft	10 to 20 ft	
Entering Radius	C	15 ft	5 to 15 ft	15 ft	5 to 20 ft	
Exiting Radius	D	10 ft	5 to 15 ft	10 ft	5 to 20 ft	
Curb Cut	R	26 ft	20 to 40 ft	Not Applicable		
The standard shall be used unless engineering judgment determines that another dimension within the range is more suitable for a particular site or a special condition is approved by the WCRC.						

Washtenaw County (MI) Rd. Comm., Procedures & Regs. for Permit Activities, p. 39, 2006

2. The design standards in this table differ according to land-use category and associated driveway traffic volumes.

Driveway Traffic Category	Average Daily Traffic Using Driveway	Peak Hour Traffic Using Driveway	With Two-Way Access	With One-Way Access
Residential	0 – 100	0 – 10	20* ft. – 30** ft.	NA
Low Volume Commercial/Industrial	< 1500	< 150	28 ft.** - 42 ft.***	20 ft.*
Medium Volume Commercial/Industrial	1,500 – 4,000	150 – 400	42 ft.*** - 54 ft.****	20 ft.* - 30 ft.**
High Volume Commercial/Industrial	> 4000	> 400	Determined through a traffic study - normally 42 ft. or greater	Generally not applicable
* One-lane driveways.				
** Driveway striped for two lanes.				
*** Driveway striped for three lanes.				
**** Driveway striped for four lanes.				
MoDOT Engr. Policy Guide 940.16, Tab. 940.16.3, Feb. 2009				

3. The design standards in this table differ according to rural or urban environment, and for different driveway traffic volumes.



ELEMENT DESCRIPTION	URBAN (CURB & GUTTER)			RURAL		
	1-20 Trips/Day or 1-5 Trips/Hour	21-600 Trips/Day or 6-60 Trips/Hour	601-4000 Trips/Day ■ or 61-400 Trips/Hour	1-20 Trips/Day or 1-5 Trips/Hour	21-600 Trips/Day or 6-60 Trips/Hour	601-4000 Trips/Day ■ or 61-400 Trips/Hour
		2-Way □	2-Way □		2-Way □	2-Way □
CONNECTION WIDTH W	12' Min. 24' Max.	24' Min. 36' Max. ☆	24' Min. 36' Max. ☆	12' Min. 24' Max.	24' Min. 36' Max. ☆	24' Min. 36' Max. ☆
FLARE (Drop Curb) F	10' Min.	10' Min.	N/A	N/A	N/A	N/A
RETURNS (Radius) R & U	N/A	△	25' Min. 50' Std. 75' Max.	15' Min. 25' Std. 50' Max.	25' Min. 50' Std. 75' Max.	25' Min. 50' Std. (Or 3-Centered Curves)
ANGLE OF DRIVE Y		60°-90°	60°-90°		60°-90°	60°-90°
DIVISIONAL ISLAND (Throat Median)		4'-22' Wide	4'-22' Wide		4'-22' Wide	4'-22' Wide
SETBACK G	12' Min., All categories. See General Note No. 5.					

■ Street or road intersection design, with possible auxiliary lanes and channelization, may be necessary. Intersection design, with possible auxiliary lanes and channelization, should be considered for connections with more than 4000 trips/days.

□ "2-Way" refers to one "in" movement and one "out" movement i.e. not exclusive left or right turn lanes on the connection.

☆ When more than 2 lanes in the turnout connection are required, the 36' max. width may be increased to relieve interference between entering and exiting traffic which adversely affects traffic flow. These cases require documented site specific study and design.

△ Small radii may be used in lieu of flares as approved by the Department.

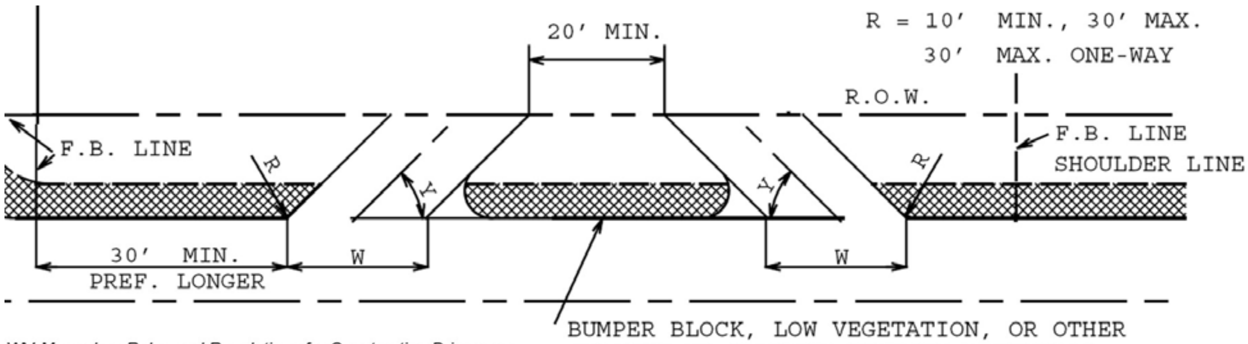
DESIGN NOTE: 1-Way connections will be designed to effectively eliminate unpermitted movements.

NOT INTENDED FOR FULL INTERSECTION DESIGN

SUMMARY OF GEOMETRIC REQUIREMENTS FOR TURNOUTS

Fla. DOT Design Stds. 515, 1/6, 2006

4. An example of angled one-way driveways.



WV *Manual on Rules and Regulations for Constructing Driveways on State Hwy. Rights-of-Way*, p. 63, May 2004

Example Design Guidelines: Connection or Throat Length, Channelization

The exhibits in this section illustrate concepts or designs related to connection length (i.e., throat length, connection depth) and channelization.

1. This excerpt explains the need for connection length design criteria.

11.4.4 Connection Depth/Throat Length. Adequate entrance throat length, coupled with appropriate on-site traffic control, helps to prevent a condition in which vehicles queue back into the State highway at the access point. Throat length is measured from the proposed edge of the highway to the first on-site intersection or vehicular conflict point. The edge of the highway shall be determined based on the ultimate highway typical section, where future widening is anticipated.

A. The minimum throat lengths in **Table 11.4.4** shall be provided where feasible and reasonable, as determined by SHA, for the principal site access point(s). Additional length may be appropriate for primary highways and other high volume, high speed arterial routes.

B. A queuing analysis may be required to determine the necessary throat length for larger commercial sites. The required length may be governed by queuing of inbound or outbound vehicles, or both.

C. In order for entrance throats to function properly, traffic entering larger commercial sites shall be given right-of-way at the intersection(s) with drive aisles, through appropriate signing and pavement markings.

D. The minimum acceptable throat length for commercial entrances under any circumstances shall be adequate to establish the standard entrance layout. For example, an entrance with a 30' radius implies at least a 30' throat length. An entrance with a 10' radius implies at least a 10' throat length.

E. Entrance throats shall be continuous, with no intersecting drive aisles, for the specified length.

F. Where site conditions preclude construction of the normally required deceleration lane, additional throat length may be required to assure satisfactory operation of the access point without stacking of vehicles into the State highway.

Table 11.4.4 Minimum Throat Length for Commercial/Industrial Entrances

Type of Development	Min. Throat Length(ft)
Regional Shopping Malls	250
Community Shopping Center (Supermarket, drug store, other stores)	120
Small Strip Shopping Center	30
Regional Office Park	250
Office Building/Professional Center	80
Small Commercial Development Sites	30

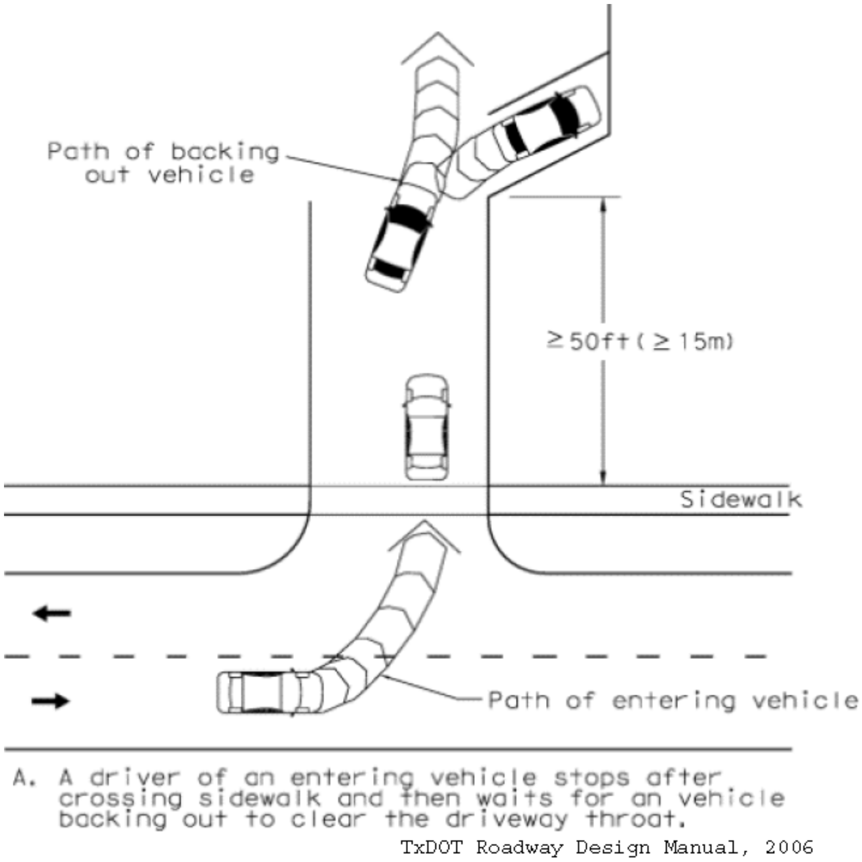
MD SHA *State Hwy. Access Manual*

4. This excerpt provides general guidance for the design of a driveway median and connection depth.

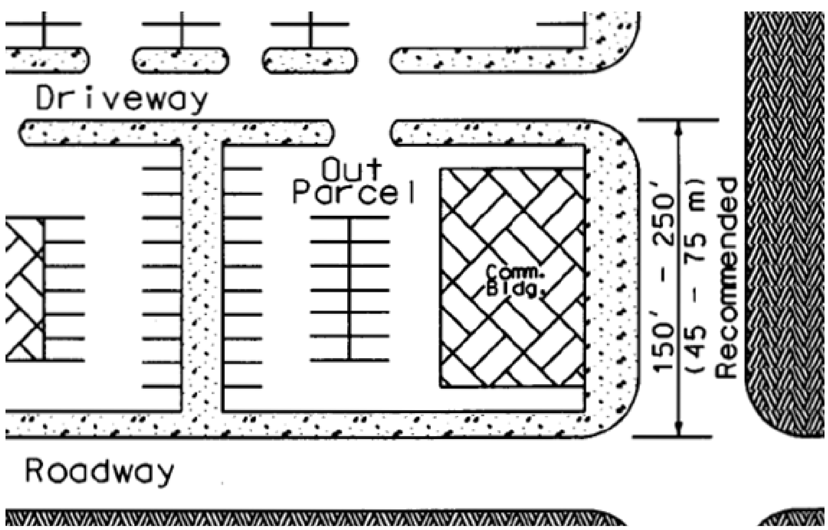
5) Medians. Where a divided entrance separating entering and exiting traffic is utilized, the median shall be between 4 and 18 feet wide and extend into the property as far as necessary to promote smooth traffic patterns. The median shall begin at the edge of the normal shoulder in an uncurbed section or 4 to 10 feet from the face of the curb in a curbed section.

Illinois, Section 550.80 Industrial-Commercial-Recreational High-Volume
Traffic Generator Driveway Requirements (Illustration G)

3. an illustration that depicts one of the traffic problems that can result from inadequate connection length



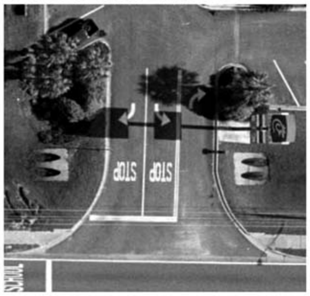
4. This standard design drawing included a dimension recommending a minimum connection length.



TYPICAL ACCESS TO OUTPARCEL SC ARMS p. C-9, 1996

5. This excerpt relates the need for driveway channelization to driveway width.

Tip – use pavement markings when driveways are 36 ft or more



Excessive width can be a problem to both drivers and pedestrians. **If a driveway is over 36 ft width, pavement markings or channelization is generally needed** to help guide the driver to the appropriate portion of the driveway.

Without the guidance of markings, drivers exiting a driveway tend to position themselves left of the driveway center. Double yellow paint lines help in guiding exiting drivers to the proper exit position. This helps ensure that the intended driveway width is available to drivers making an entry maneuver.

Source: Transportation and Land Development, 2002, Stover

Fla. DOT, *Driveway Handbook*, p. 30, Mar. 2005

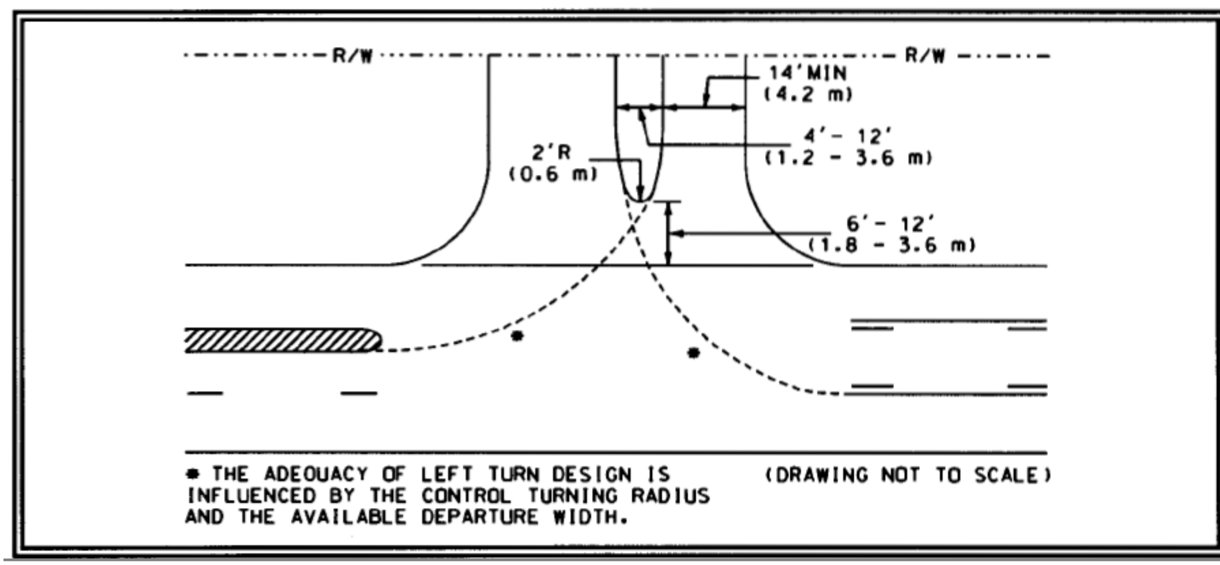
6. This excerpt provides direction for the design of the driveway median, and also highlights the need to control a landscaping so as to not block the driver's line of sight.

3G-6 *Driveway Medians*

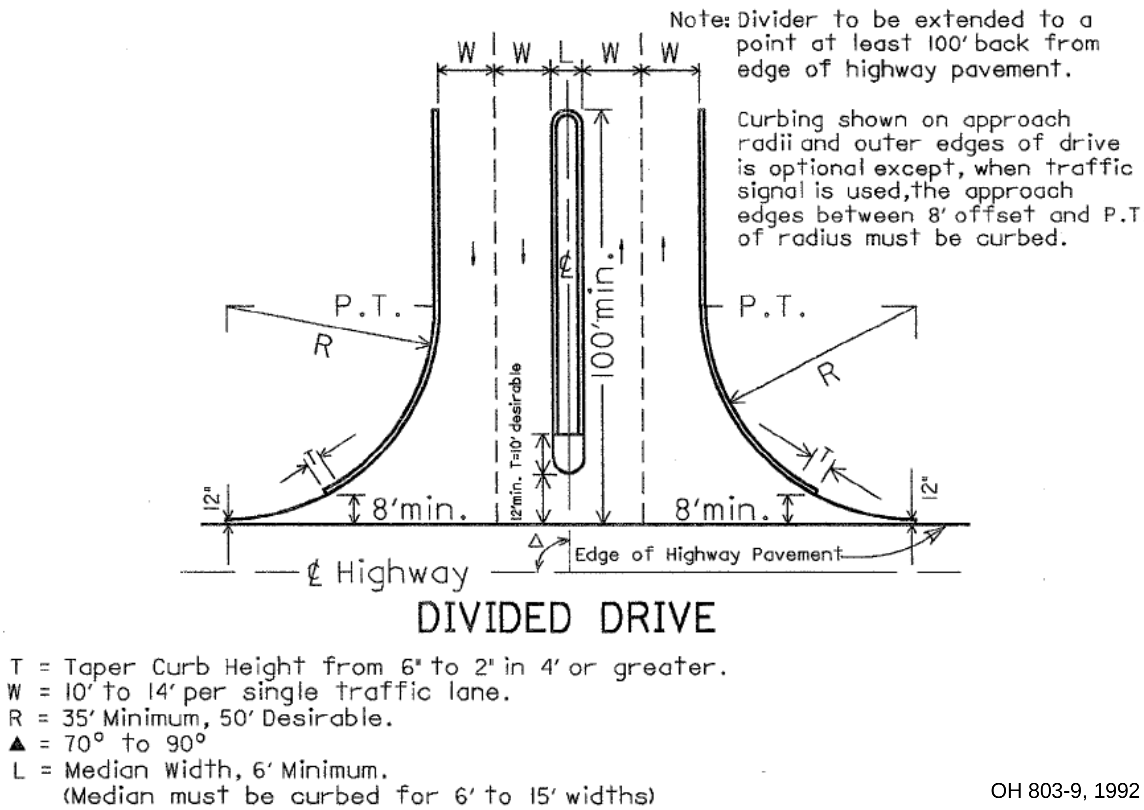
When a median is used to separate opposing traffic on a driveway, the part of the median within the right-of-way shall have a minimum width of 4 feet (1.2 m) and a maximum width of 12 feet (3.6 m). The nose of the median shall be set back 6 to 12 feet (1.8 to 3.6 m) from the edge of the roadway. Landscape plants on the median and within 25 feet (7.5 m) of the roadways should be limited to low growing plants not exceeding 2½ feet (760 mm) in height. See also subsection 3A-3 and section 4E regarding sight distance and landscaping respectively. When the median width is larger than 4 feet (1.2 m), the nose shall be defined with a 2 foot (0.6 m) radius and the control turning radius. See figure 3-7.

FIGURE 3-7 DRIVEWAY MEDIAN DESIGN

SC ARMS p. 23, 1996



7. This is an agency's standard design for one category of driveway median.



OH 803-9, 1992

SHOPPING CENTER & INDUSTRIAL DRIVE DESIGNS

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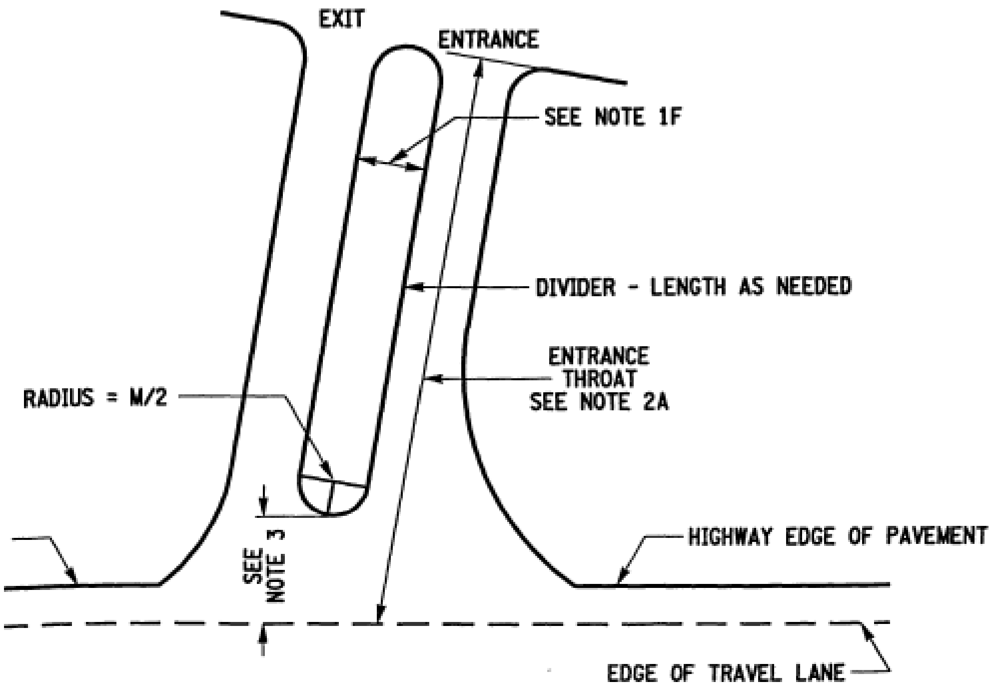
8. This excerpt explains the need for connection length design criteria. It is accompanied by the agency's typical design drawing.

5A.6.1.2 Driveway Throat

The driveway throat is an access controlled portion of the driveway entrance that helps delineate the driveway and provides space to store entering and exiting vehicles. The access control between the parking areas and the edge of the driveway throat should be achieved using curbing, wide turfed areas, shrubs, median barrier, or other physical means (i.e., pavement markings and signs are not enough). The length selected for a particular driveway (measured along the driveway centerline) should be based on the operational, safety, and construction costs. The entrance should allow all entering traffic to pull off the highway before stopping. The exit throat length should prevent exiting vehicles from obstructing entering traffic, which could cause entering traffic to queue back onto the highway. The driveway throat should extend beyond the highway right of way line, if necessary.

NYS DOT *Policy and Stds. for the Design of Entrances to State Hwys.*, 2003

DIVIDED COMMERCIAL DRIVEWAY WITH A MEDIAN



2. COMMERCIAL DRIVEWAY THROAT (MEASURED ALONG DRIVEWAY ENTRANCE):

A. TWO-WAY DRIVES AND ONE-WAY DRIVES SEPARATED BY A MEDIAN: THE MINIMUM DEPTH OF ENTRANCE THROAT SHOULD BE 9 m (30') FOR MINOR COMMERCIAL DRIVES AND 15 m (50') FOR MAJOR COMMERCIAL DRIVES.

NYS DOT *Policy and Stds. for the Design of Entrances to State Hwys*, Fig. 5A-1, 2003

Examples Design Guidelines: Driveway Intersection with Sidewalk and Roadway

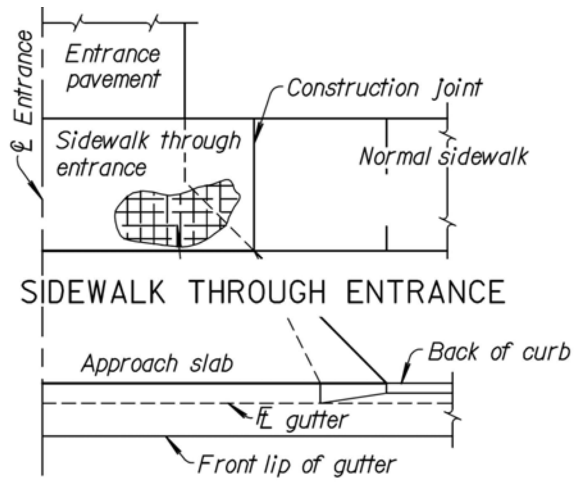
The following examples from transportation agency documents illustrate a range of practices for the combined design of the sidewalk location, sidewalk elevation, and curb transition treatment where the driveway intersects the sidewalk and the roadway.

The exhibits in the first group illustrate sidewalk routing across the driveway (this concept is also a component of some exhibits in the second and third groups). The exhibits in the second group show design treatments when the sidewalk is adjacent or attached to the curb. The exhibits in the third group show design treatments when the sidewalk is set back or detached from the curb. In both the second and the third groups, the exhibits are arranged in the general sequence of more-restrictive (for the turning vehicle) to less-restrictive.

The treatments devised to limit sidewalk cross slope in the area where the driveway intersects the sidewalk and the roadway in a confined space often incorporate one or more of these strategies::

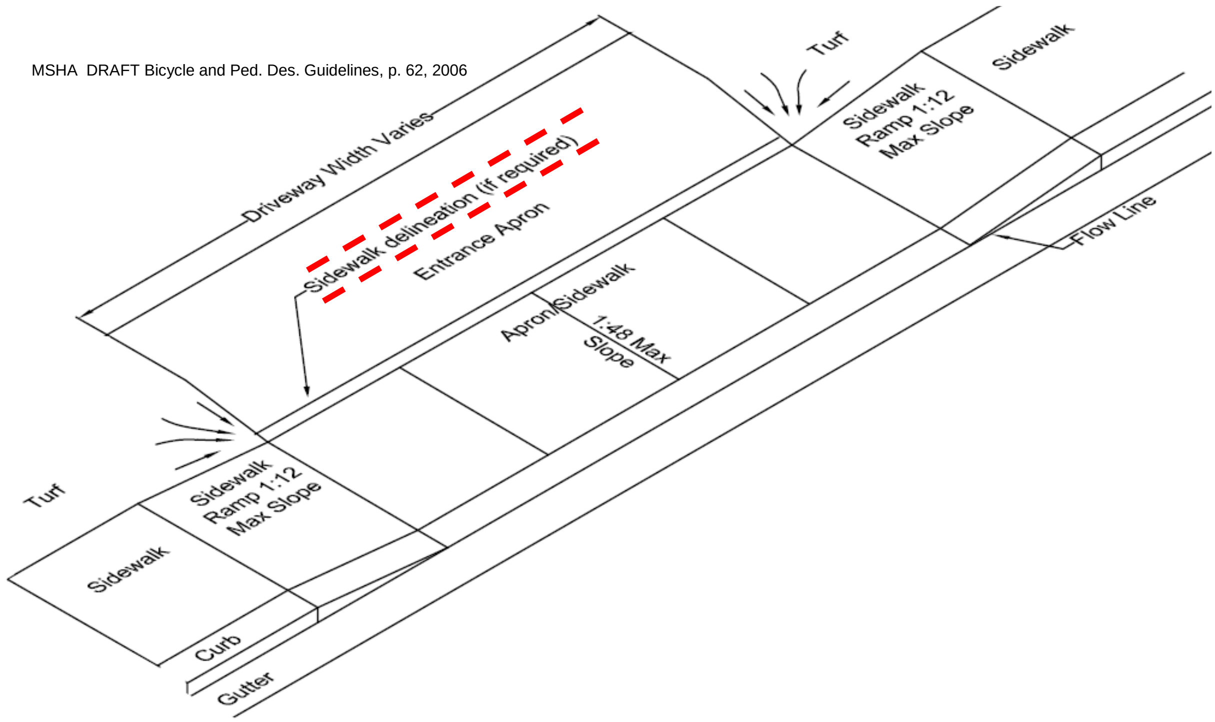
1. rapid driveway elevation change;
2. depressed sidewalk; or
3. realigned sidewalk.

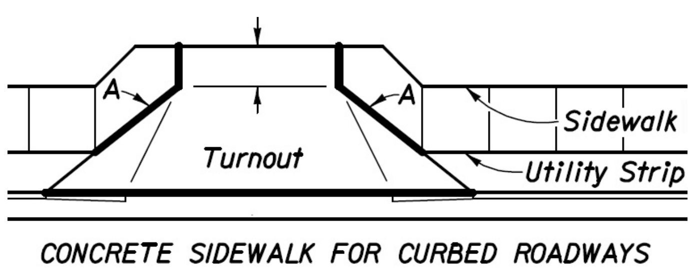
Sidewalk Routing Across the Driveway



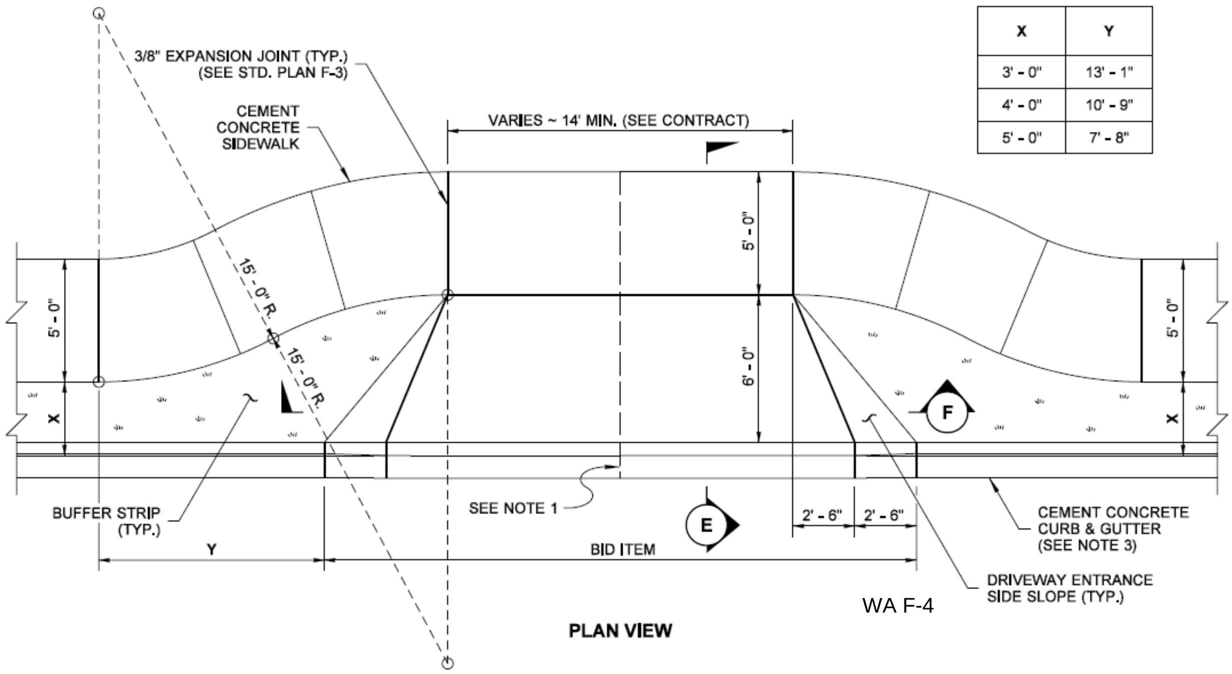
KS DOT RD 725, 2005

MSHA DRAFT Bicycle and Ped. Des. Guidelines, p. 62, 2006



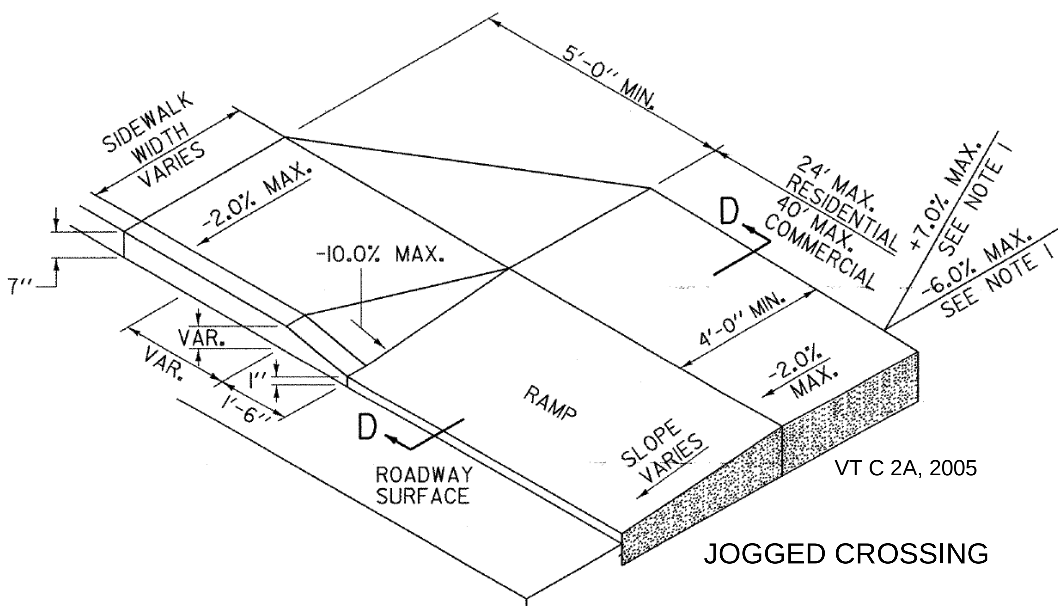


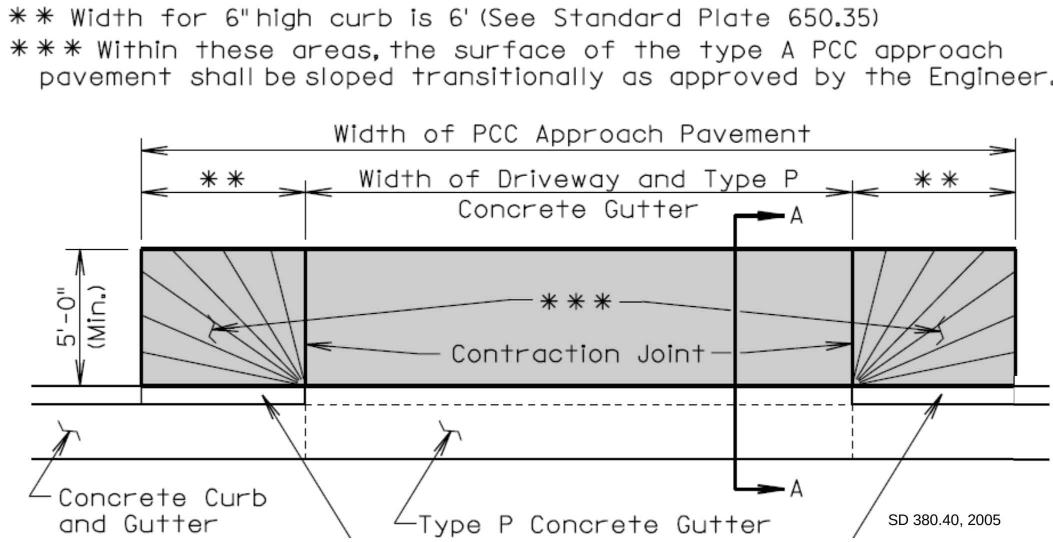
FDOT Design Stds. 310, 1/2, 2006



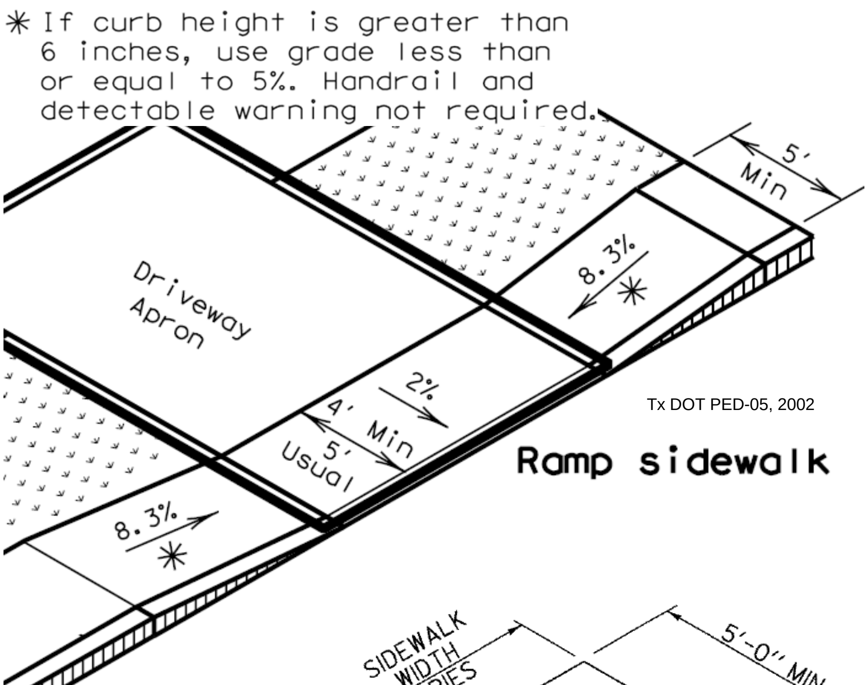
X	Y
3' - 0"	13' - 1"
4' - 0"	10' - 9"
5' - 0"	7' - 8"

Design Treatments, Sidewalk Adjacent to Curb



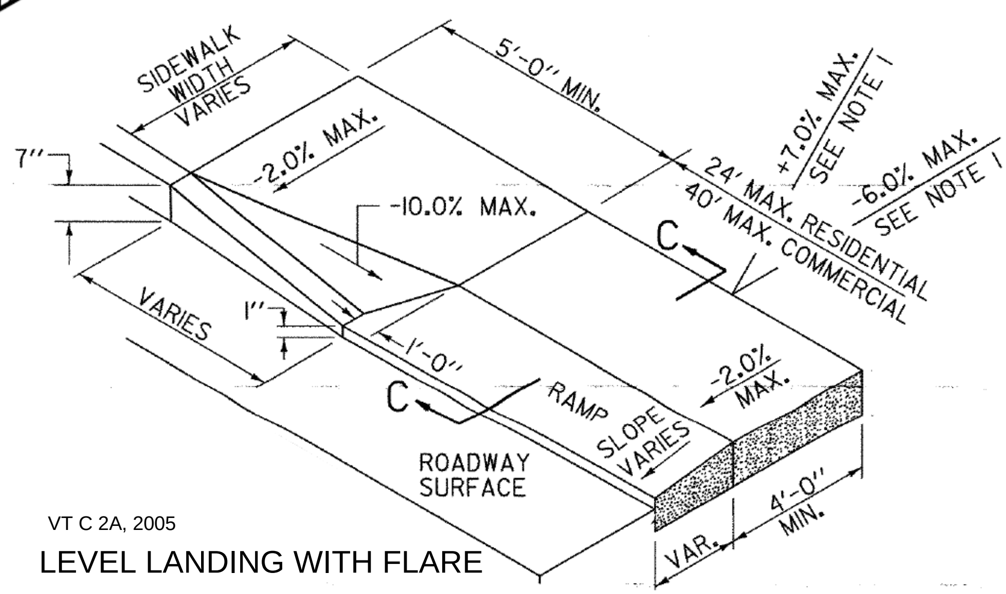


SD 380.40, 2005



Tx DOT PED-05, 2002

Ramp sidewalk



VT C 2A, 2005

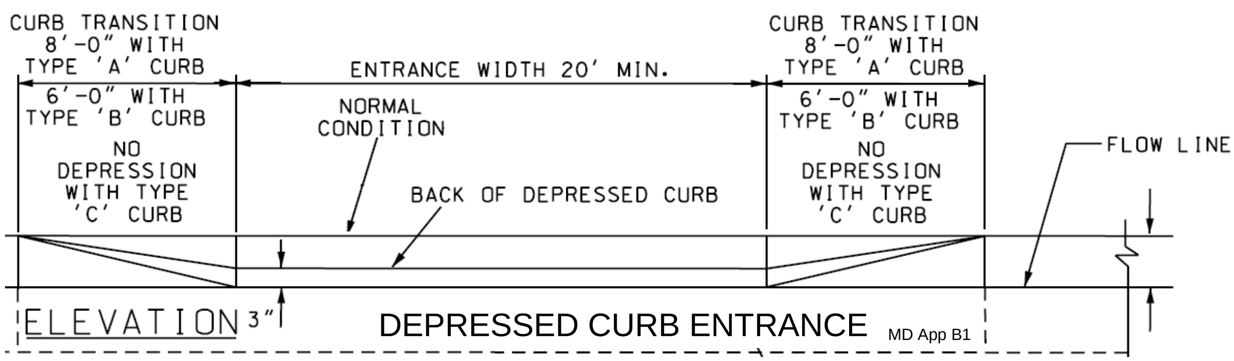
LEVEL LANDING WITH FLARE

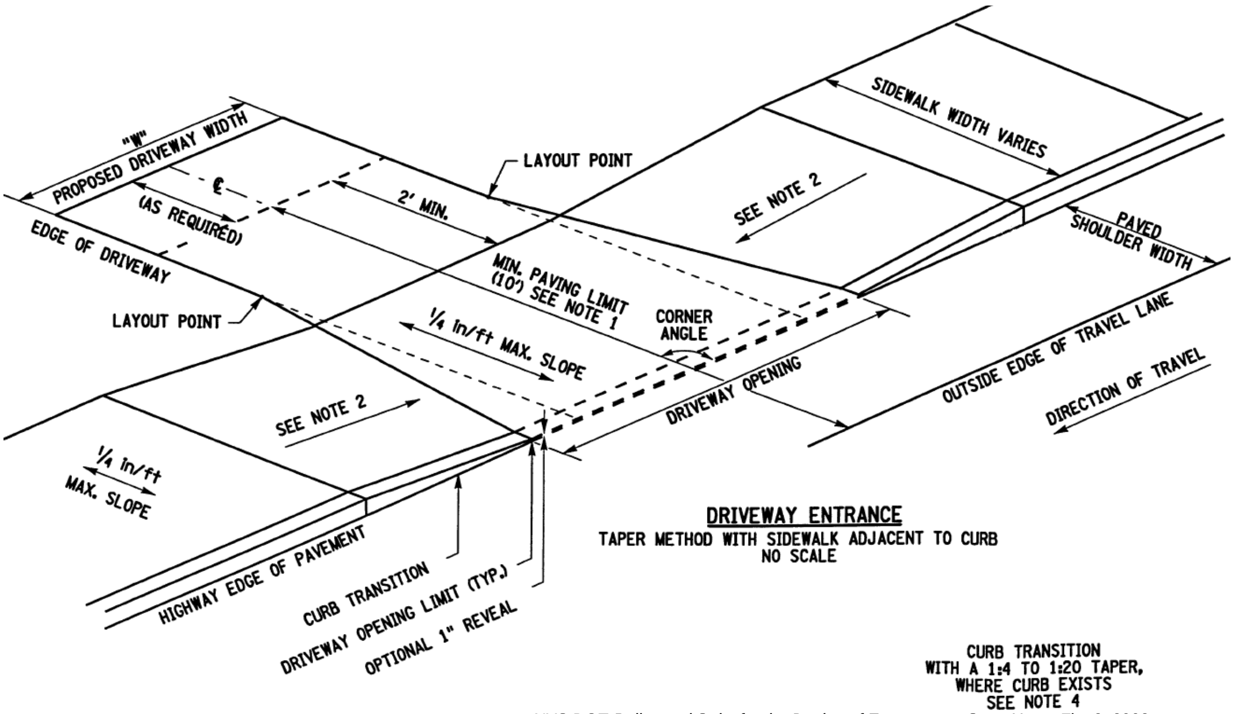
11.1.1 Depressed Curb Entrances.

A. Description. Depressed curb entrances offer the most compact entrance layout and accommodate two-way movements. Their integral flared sides are equivalent to approximately a 5' radius return. This limits the speed of vehicles turning into or out from the entrance. The merits of this inherent speed control feature, particularly for vehicles turning across sidewalk areas and entering the site, must be weighed against the effects of greater speed reduction required for vehicles on the highway approaching the entrance to make turns. Also, the need to accommodate vehicle turning movements may result in excessive overall entrance width. Depressed curb entrances provide no directional control.

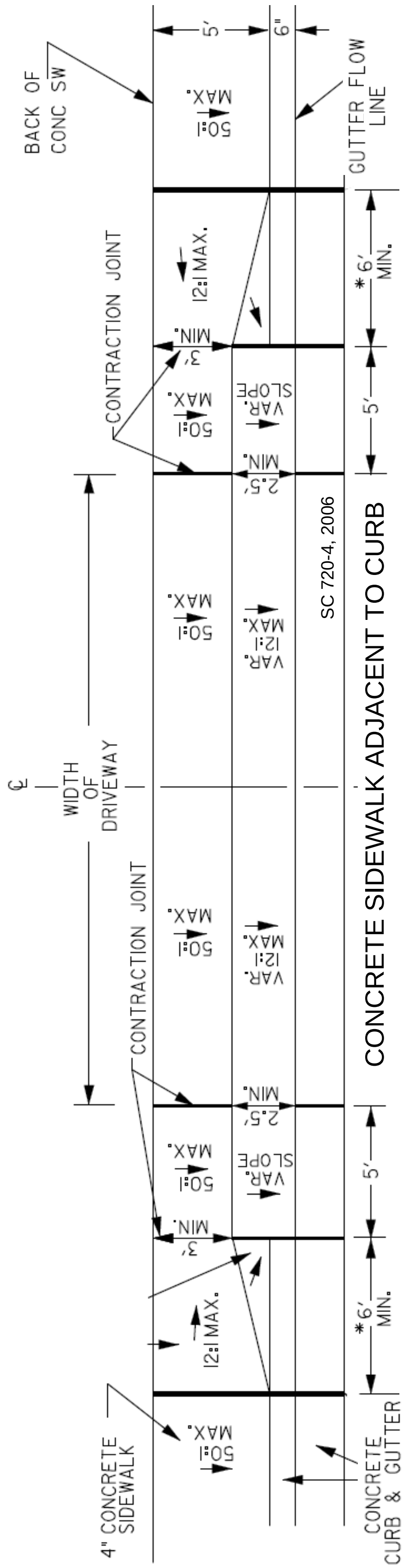
B. Applications.

- Depressed curb entrances are appropriate for use along lower speed highways in urban settings, where significant pedestrian traffic is anticipated and highway capacity issues are not a primary concern. The posted speed should be no higher than 40 mph.
- The use of depressed curb entrances is restricted to undivided highways and divided highways that have a raised median.
- Depressed curb entrances are not appropriate for one-way entrances.
- Depressed curb entrances should be reserved for sites that will not generate sufficient traffic to have a significant effect on the highway traffic stream.
- Depressed curb entrances shall not be used on primary highways, in the interest of minimizing traffic interference due to turning vehicles.
- Refer to the typical detail in Appendix B.

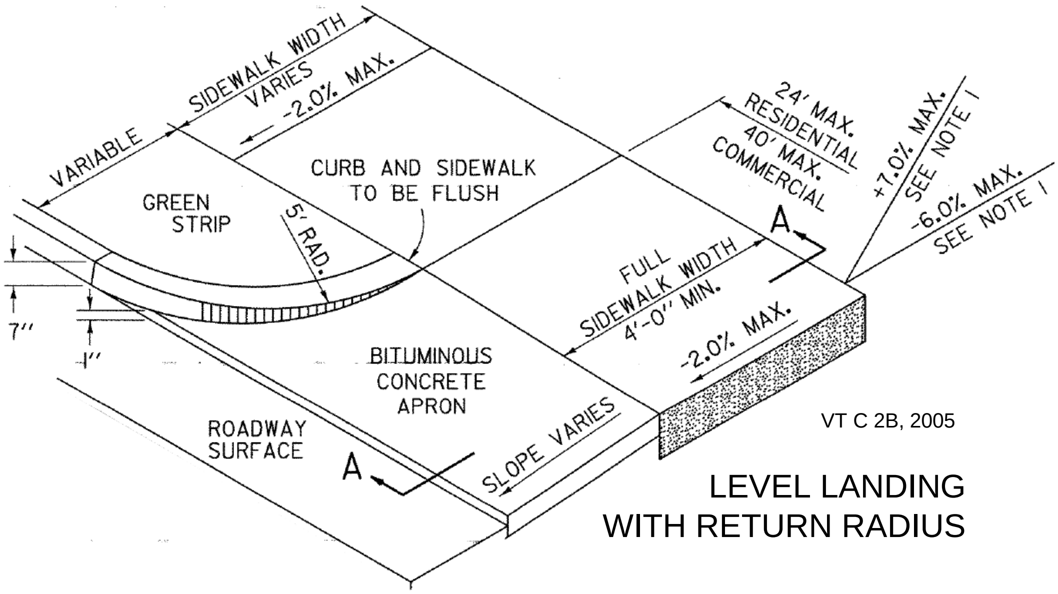




NYS DOT *Policy and Stds. for the Design of Entrances to State Hwys*, Fig. 2, 2003

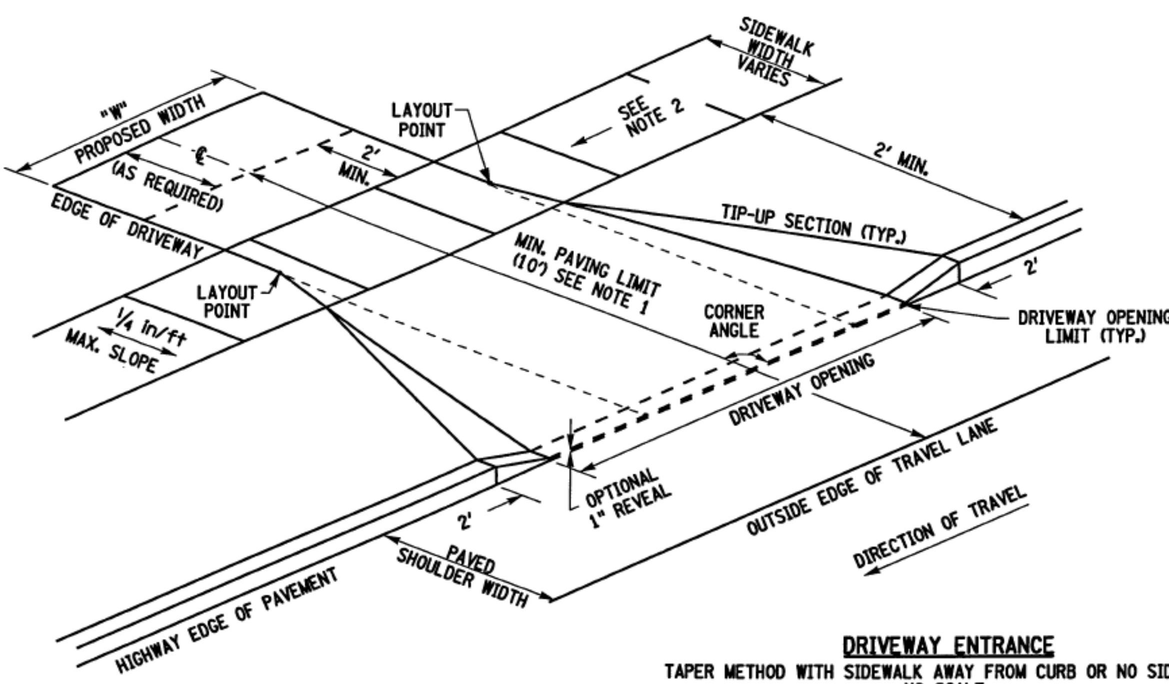

CONCRETE SIDEWALK ADJACENT TO CURB
SC 720-4, 2006
BACK OF CONC SW
GUTTER FLOW LINE
CONTRACTION JOINT
CONTRACTION JOINT
WIDTH OF DRIVEWAY
4" CONCRETE SIDEWALK
CONCRETE CURB & GUTTER
50:1 MAX.
12:1 MAX.
VAR. SLOPE
VAR. 12:1 MAX.
3' MIN.
2.5' MIN.
* 6' MIN.
5'
6"

Design Treatments, Sidewalk Set Back from Curb



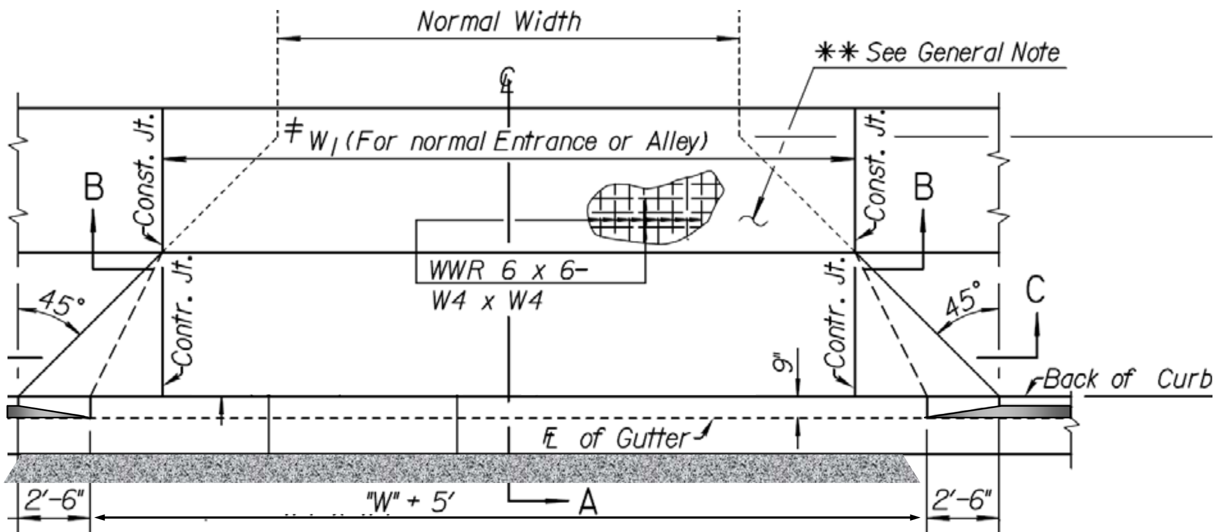
VT C 2B, 2005

LEVEL LANDING
WITH RETURN RADIUS

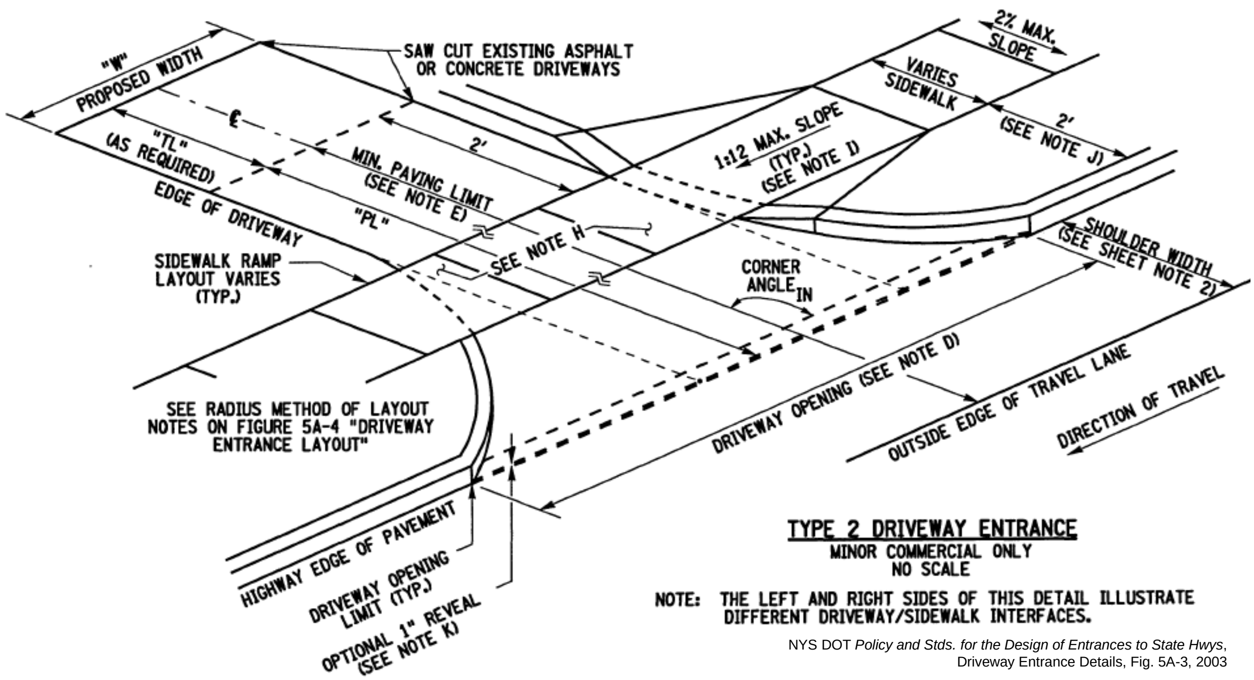


DRIVEWAY ENTRANCE
TAPER METHOD WITH SIDEWALK AWAY FROM CURB OR NO SIDEWALK
NO SCALE

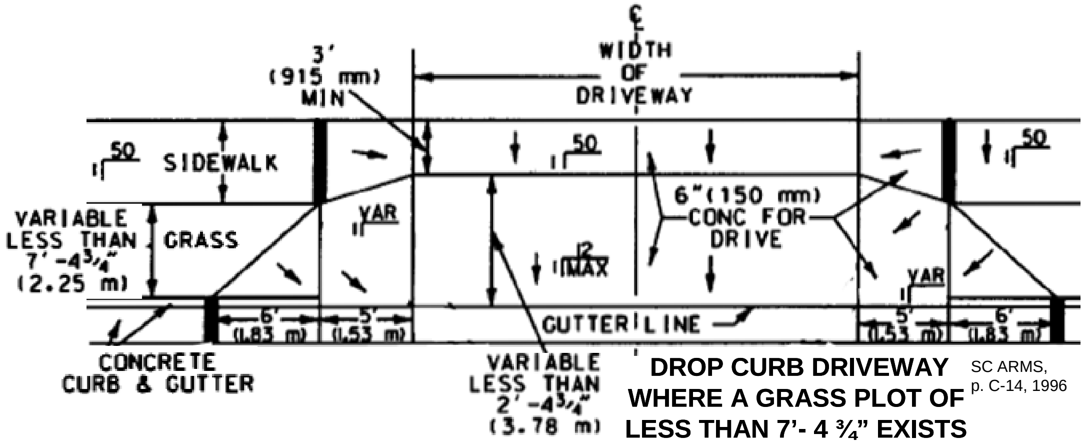
NYS DOT *Policy and Stds. for the Design of Entrances to State Hwys*, Fig. 2, 2003



TYPICAL PLAN FOR NORMAL ENTRANCE PAVEMENT KS RD 726, 2005

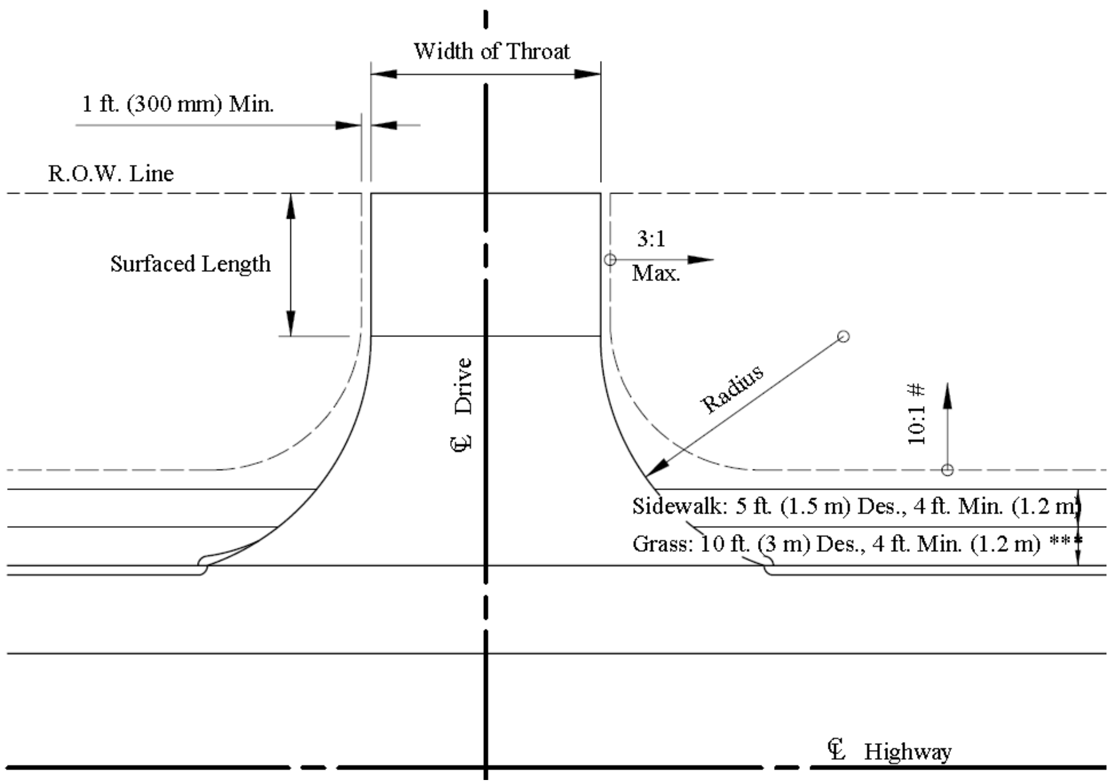


NYS DOT *Policy and Stds. for the Design of Entrances to State Hwys*,
Driveway Entrance Details, Fig. 5A-3, 2003



DROP CURB DRIVEWAY WHERE A GRASS PLOT OF LESS THAN 7'- 4 ¾" EXISTS

SC ARMS, p. C-14, 1996



URBAN DRIVEWAYS

NE *Roadway Design Manual*, p. 4-34, 2006

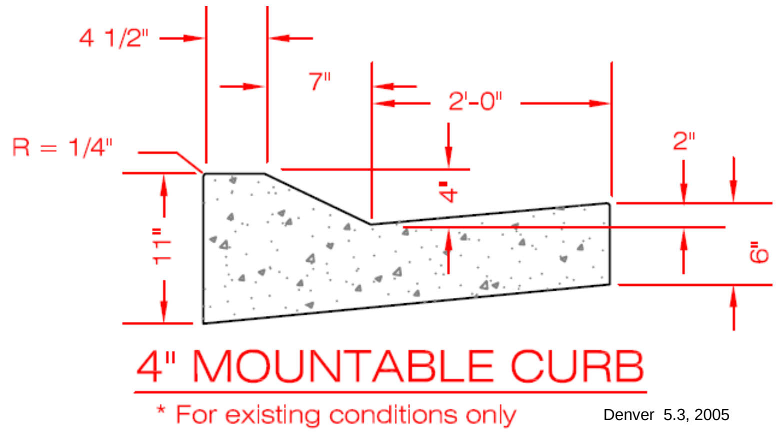
10:1 des., 6:1 min. within lateral obstacle clearance distance, then transition to 3:1 in 15 ft. (4.5 m).

*** 0 ft. allowed in urban business districts with sidewalks of 6 ft. min. (1.8 m) width.

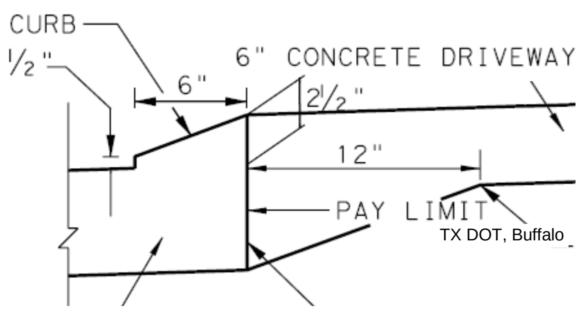
Example Design Guidelines: Vertical Alignment and Curb Modification at Driveway

The exhibits and excerpts in this section illustrate a range of treatments for the curb at the driveway intersection, and for the vertical alignment of the driveway itself. Some of the material also addresses the issue of confining runoff flow in the gutter.

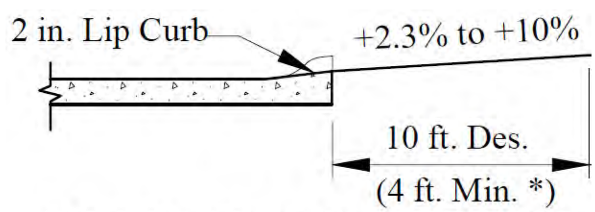
The initial exhibits in this section are those having a scope limited to the immediate curb area, and are presented in a sequence that ranges from a more-abrupt to a less-abrupt curb crossing. These are followed by exhibits that also address driveway gradient and vertical curvature.



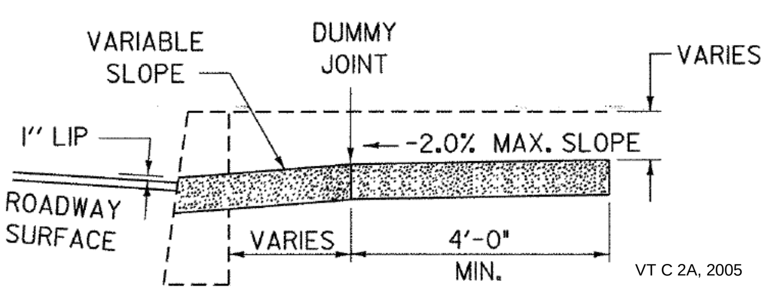
Denver 5.3, 2005



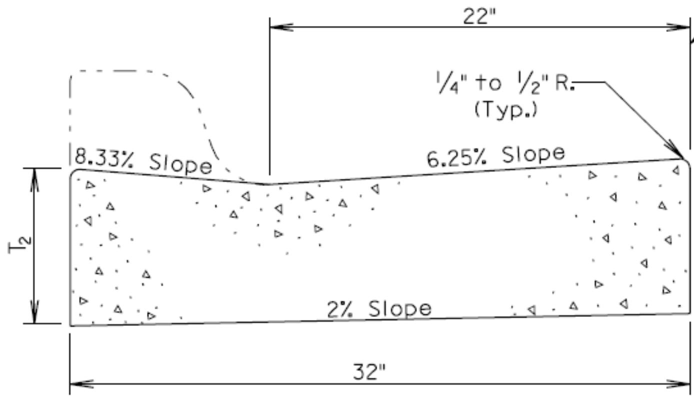
TX DOT, Buffalo



NE Dept. of Rds. *Rdwy. Des. Manual*, p.4-34, July 2006



VT C 2A, 2005

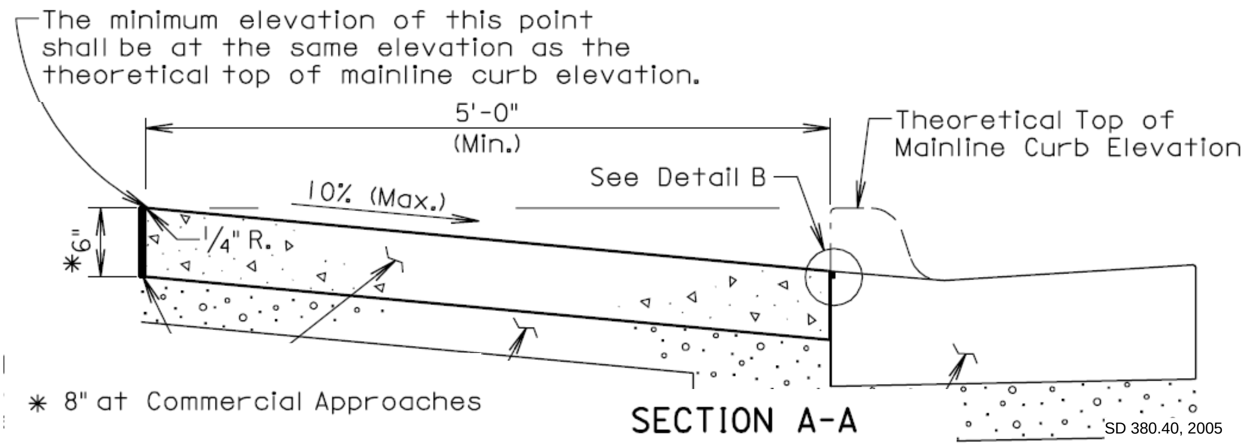


Type	T1 (Inches)	T2 (Inches)	Cu. Yd. Per Lin. Ft.	Lin. Ft. Per Cu. Yd.
P6	6	6 1/8	0.046	21.7
P7	7	7 1/8	0.055	18.2
P8	8	8 1/8	0.063	15.9
P8.5	8.5	8 5/8	0.067	14.9
P9	9	9 1/8	0.071	14.1
P9.5	9.5	9 5/8	0.075	13.3
P10	10	10 1/8	0.079	12.7
P10.5	10.5	10 5/8	0.083	12.0
P11	11	11 1/8	0.087	11.5
P11.5	11.5	11 5/8	0.091	11.0
P12	12	12 1/8	0.095	10.5

TRANSVERSE SECTION

TYPE P CONCRETE GUTTER

SD 650.30, 2005

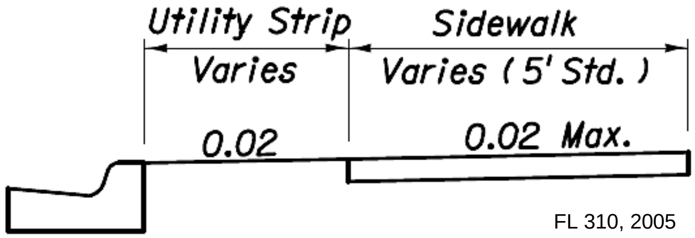


SD 380.40, 2005

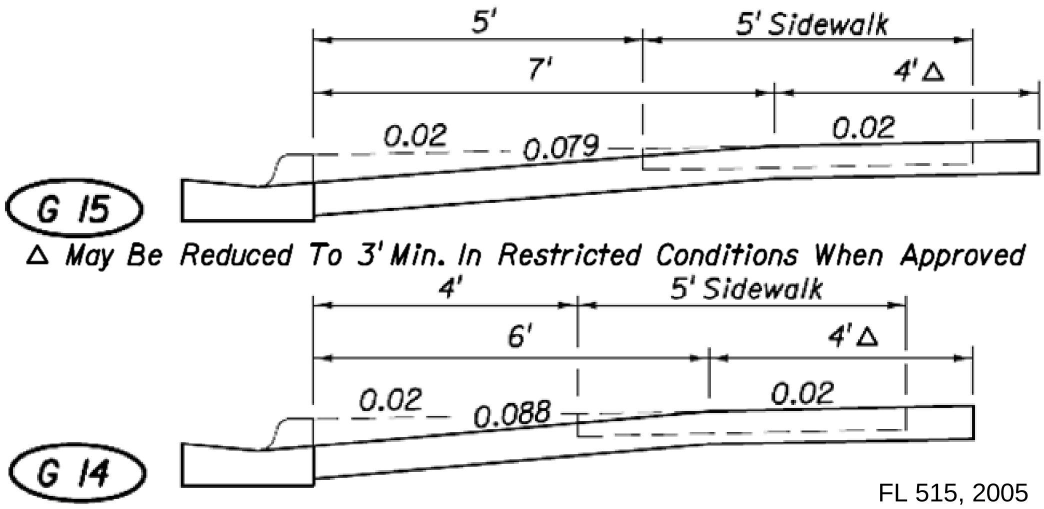
TABLE 2 MAXIMUM SLOPE		
ROADWAY CLASSIFICATION	COMMERCIAL DRIVEWAY	RESIDENTIAL DRIVEWAY
RURAL	10%	12%
URBAN	6%	8%

1. TO PREVENT DRIVEWAY GRADES FROM EXCEEDING THE VALUES IN TABLE 2 - 'MAXIMUM SLOPE', IT MAY BE NECESSARY TO DEPRESS THE SIDEWALK ACROSS THE DRIVEWAY. SIDEWALK RAMPS SHALL HAVE THE LEAST SLOPE POSSIBLE, NOT TO EXCEED A LONGITUDINAL SLOPE OF 1:12 OR A CROSS SLOPE OF 2%. WHERE THE HIGHWAY GRADE MAKES A 1:12 SLOPE IMPRACTICAL, THE RAMP LENGTH MAY BE RESTRICTED TO 15'.

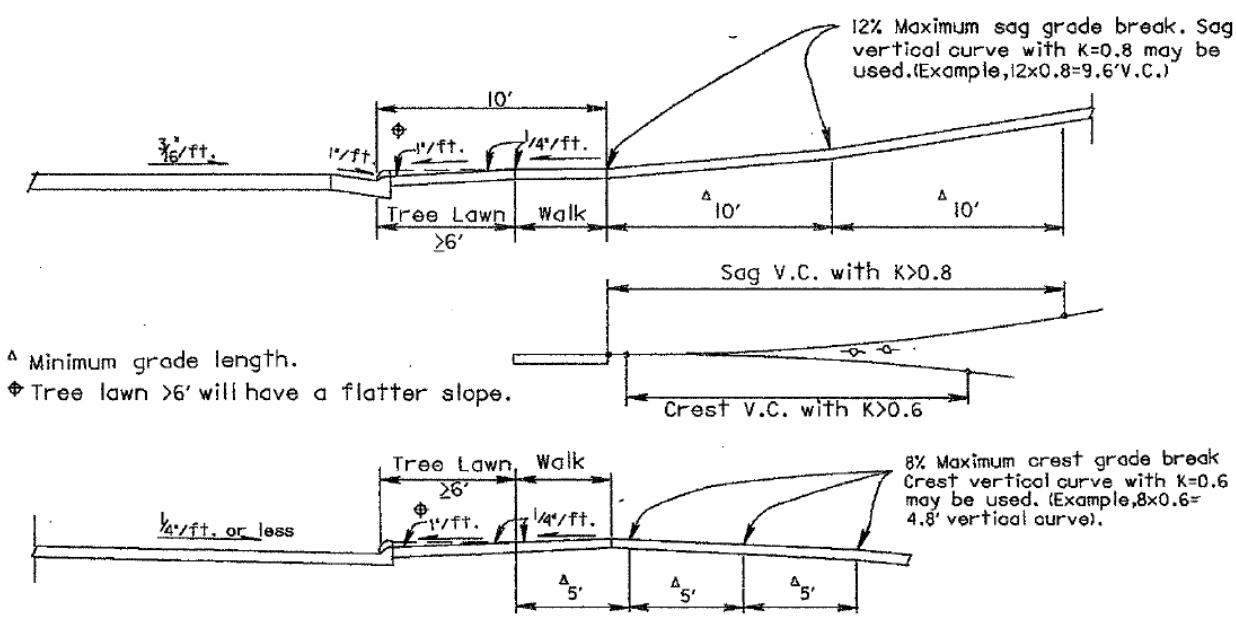
NYS DOT, *Driveway Design Guidelines*, 608-03, 1/8/09



FL 310, 2005



FL 515, 2005



URBAN RESIDENTIAL DRIVE DETAILS

OH 803-2, 1992

PROFILE/GRADE

3.19.1 If the road is curbed, the grade of the driveway shall meet the existing edge of pavement.

3.19.2 If the road is uncurbed, the grade of the driveway between the road edge of pavement and the outside edge of the shoulder shall conform to the slope of the shoulder. Where the existing shoulder is less than six feet, the grade of the existing road bed or shoulder shall be carried to a point six feet off the edge of the existing roadway surface.

3.19.3 The grade of two-way, one-way, and divided commercial driveways shall not exceed a maximum of six percent (6%).

3.19.4 The grade of residential, utility, and field driveways shall not exceed a maximum of ten percent (10%).

3.19.5 Vertical curves (15-foot minimum) shall be provided at all changes of grade of four percent (4%) or more.

3.19.6 If a sidewalk elevation must be adjusted to meet the driveway, the slope of the sidewalk shall not exceed five percent (5%).

3.19.7 A driveway profile shall be determined using the following criteria:

a) If the roadway is uncurbed, the grade of the driveway between the roadway edge of pavement and the edge of the shoulder shall conform to the slope of the shoulder.

b) If the roadway is uncurbed or if the sidewalk is more than 10 feet from the edge of the pavement or if there is no sidewalk:

i. The grade of a two-way, one-way or divided commercial driveway after it transitions from the shoulder edge shall not exceed 6%.

ii. The grade of a residential or utility structure driveway or field entrance shall not exceed 10% after it transitions from the shoulder edge.

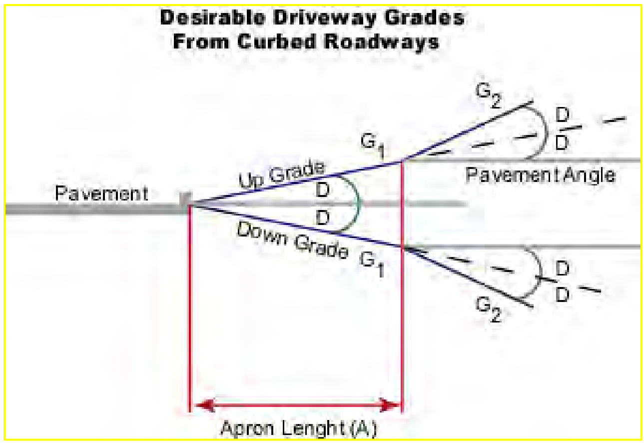
c) If the roadway is curbed and if the sidewalk is 10 feet or less from the edge of pavement, the grade of a driveway, except a directional driveway, shall be the grade required to meet the sidewalk elevation; but if that grade would exceed the maximums specified in paragraph (b), the sidewalk shall be either tilted or inclined.

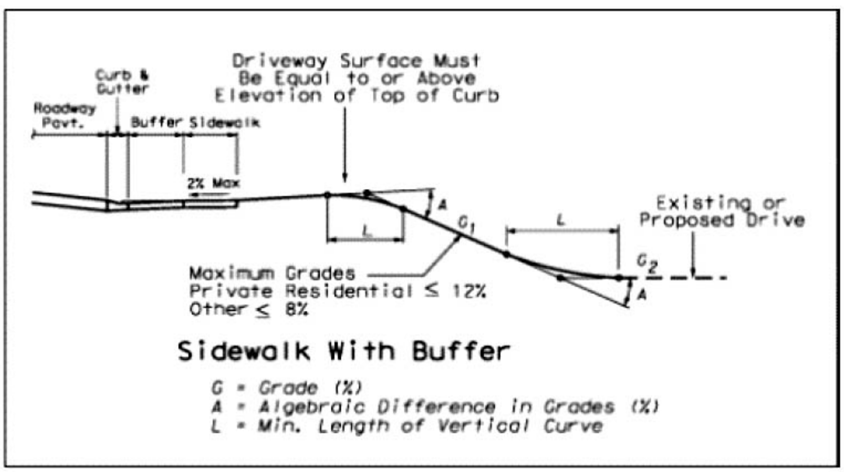
d) The grade of a directional driveway shall be designed so to provide vision of the roadway edge of pavement and the driveway surface for a distance of 100 feet along the driveway. For a driveway on an upgrade towards the roadway, a grade of 1.5% for a distance of 100 feet from the edge of the pavement is acceptable. Beyond this distance, the grade shall not exceed 6% and the differences in grades where there is a change of grade shall not exceed 3%.

Procedures & Regulations for Permit Activities, Washtenaw County Road Commission Ann Arbor, MI, 2006

Roadway Classification	Apron Length ("A" in the Diagram)	Desirable Grade Change, ("D" in the Diagram) Urban	Desirable Grade Change, ("D" in the Diagram) Rural
Major - Freeway	No driveways	No driveways	No driveways
Principal Arterial	25-30 feet	1%-4%	1%-3%
Minor Arterial	10-20 feet	1%-5%	1%-4%

MoDOT Engr. Policy Guide 940.16, Tab. 940.16.9, Feb. 2009

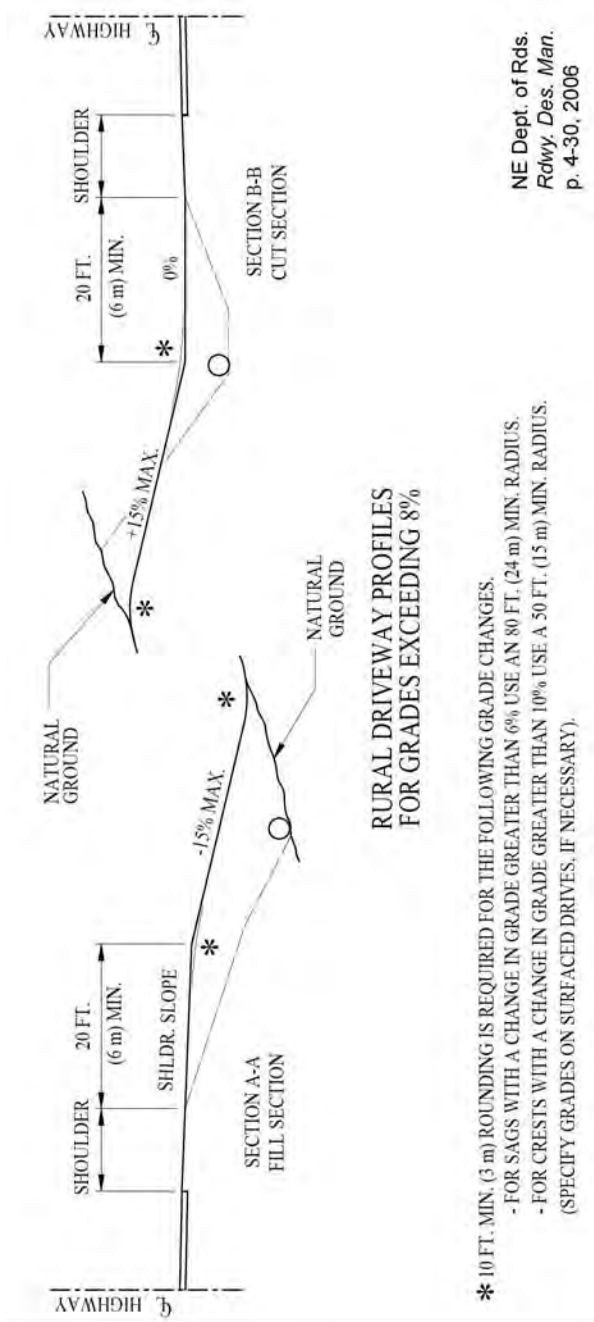




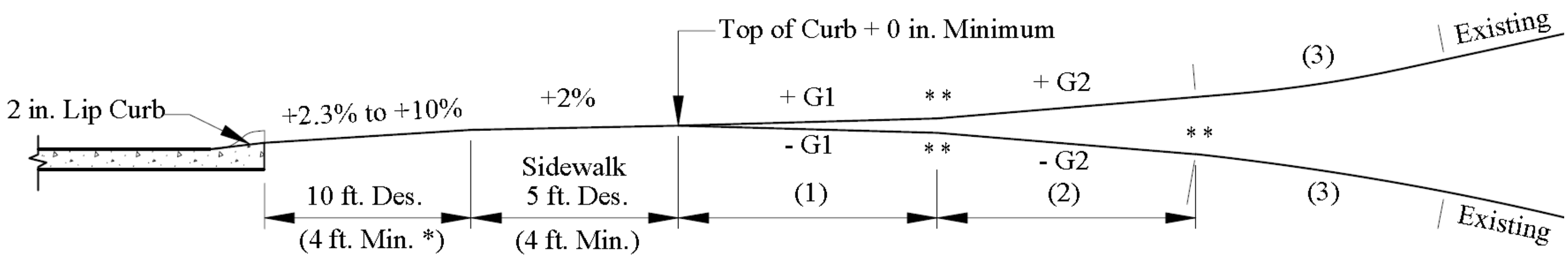
TxDOT *Rdwy. Des. Manual*, p. C-15, Oct. 2006

Driveway	Change in Grade (A)(1)
Private Residential Driveways	10%
All Other Driveways	8%
(1)Change in grade between the pavement cross-slope and the driveway apron slope	

Tx DOT Rdwy. Des. Manual, p. C-13, Oct. 2006



NE Dept. of Rds.
Rdwy. Des. Man.
p. 4-30, 2006



PROFILE URBAN DRIVEWAY WITH SIDEWALK OR FUTURE SIDEWALK
(MAXIMUM ALLOWABLE PERCENT OF GRADE)

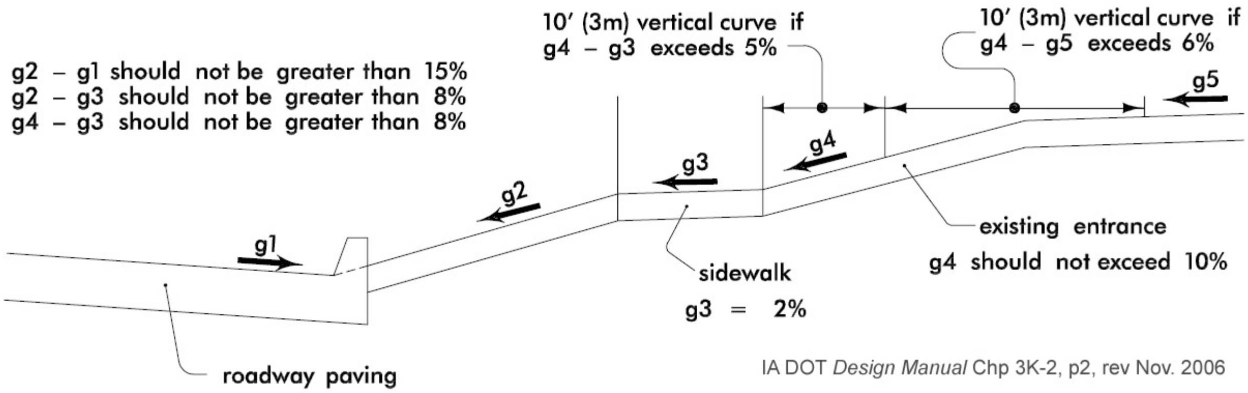
1. 10 ft. min. (3 m) is required when the existing grade is greater than 8%.
2. 10 ft. min. (3 m) is required when the existing grade is greater than 15%.
3. 10 ft. min. (3 m) rounding is required when the existing grade is greater than 22%.

* 0 ft. is allowed in urban business districts with sidewalks of 6 ft. (1.8 m) min.

** 10 ft. min. (3 m) rounding desirable for the following grade changes:
- For sags with a change in grade greater than 7% use an 80 ft. (24 m) min. radius.
- For crests with a change in grade greater than 10% use a 50 ft. (15 m) min. radius.

DRIVEWAY TYPE	G1 (MAX.)	G2 (MAX.)
COMMERCIAL, INDUSTRIAL	+/- 5%	+/- 8%
DWELLINGS (RESIDENTIAL)	+/- 8%	+/- 15%

NE *Roadway Design Manual*, p. 4-34, 2006

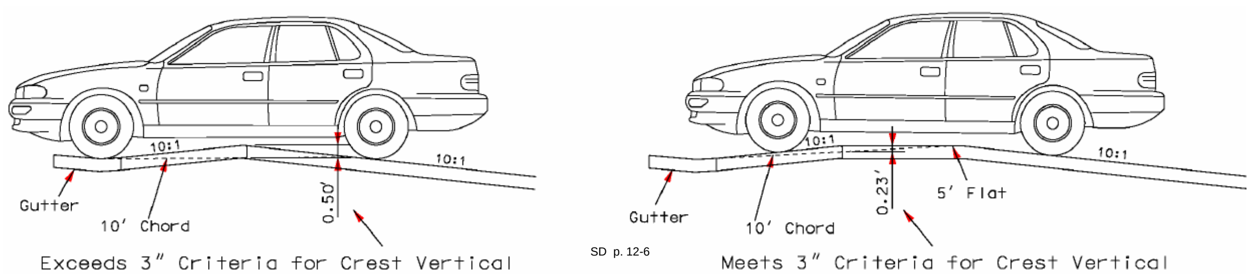


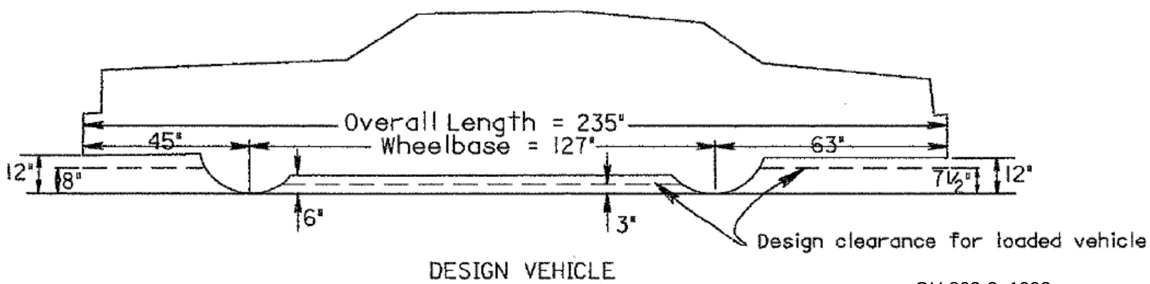
IA DOT *Design Manual* Chp 3K-2, p2, rev Nov. 2006

Examples Design Guidelines: Design Vehicle for Vertical Alignment

This section presents text and exhibits from state documents that help define the limits of allowable change of a vertical alignment.

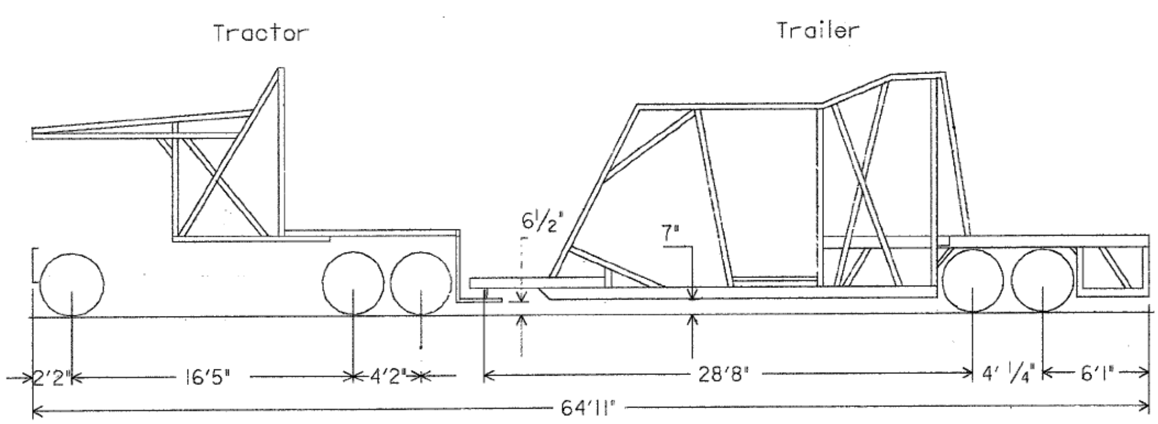
Vertical curves on driveways shall be flat enough to prevent dragging of central or overhanging portions of passenger vehicles. Crest vertical curves or humps can present a problem when the elevation behind the tie-in point for an approach is lower than the theoretical top of curb elevation. The designer must evaluate the potential of dragging on the crest vertical which should not exceed a 3” hump in a 10’ chord. The designer must also evaluate situations so the depression of a sag vertical curve does not exceed 2” in a 10’ chord. Superelevation of the roadway is an example when an evaluation of dragging must be considered for a sag vertical curve. Some possible solutions to dragging problems may be constructing a flat spot on the approach as shown below, or altering the slope from a 10:1 to a more gradual slope (SD, p 12-6).





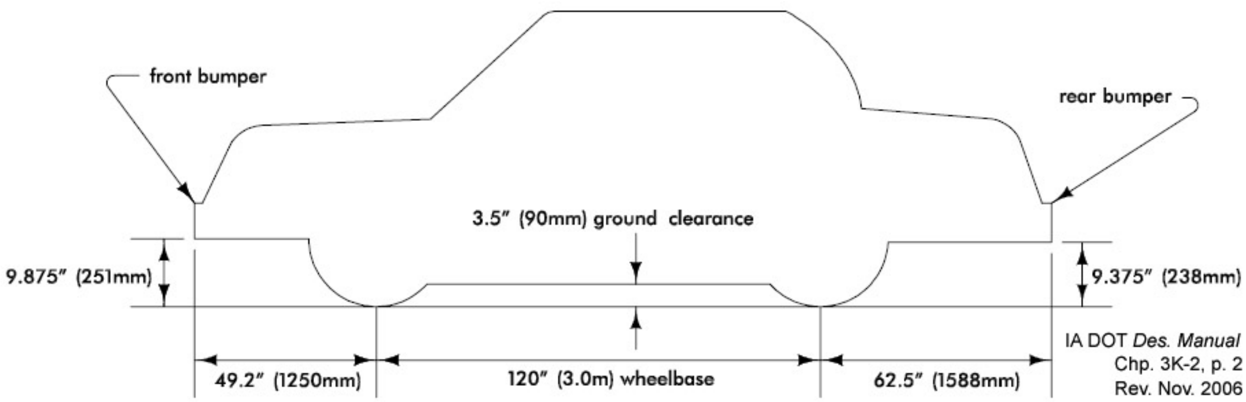
OH 803-2, 1992

URBAN RESIDENTIAL DRIVE DETAILS



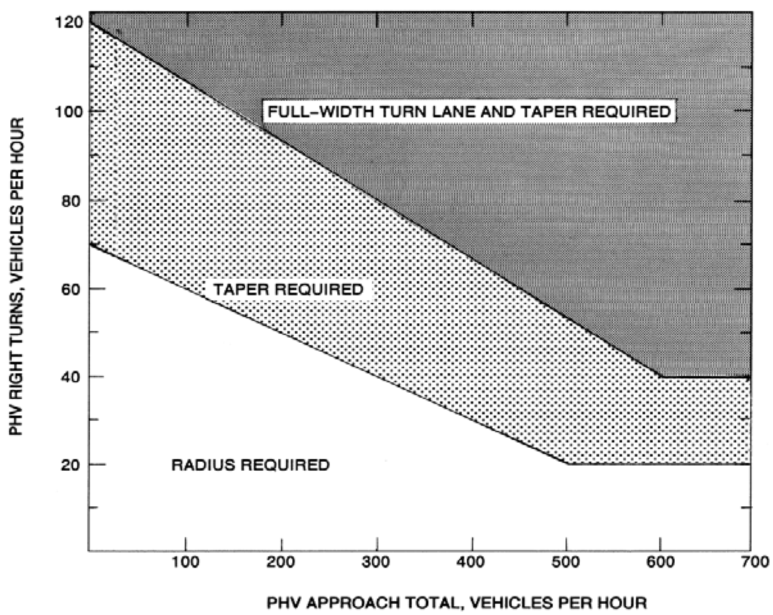
COMMERCIAL DESIGN VEHICLE

OH 804-2


front bumper
rear bumper
3.5" (90mm) ground clearance
9.875" (251mm)
9.375" (238mm)
49.2" (1250mm)
120" (3.0m) wheelbase
62.5" (1588mm)
IA DOT *Des. Manual*
Chp. 3K-2, p. 2
Rev. Nov. 2006

Examples Design Guidelines: Right-Turn Lane, Driveway Island

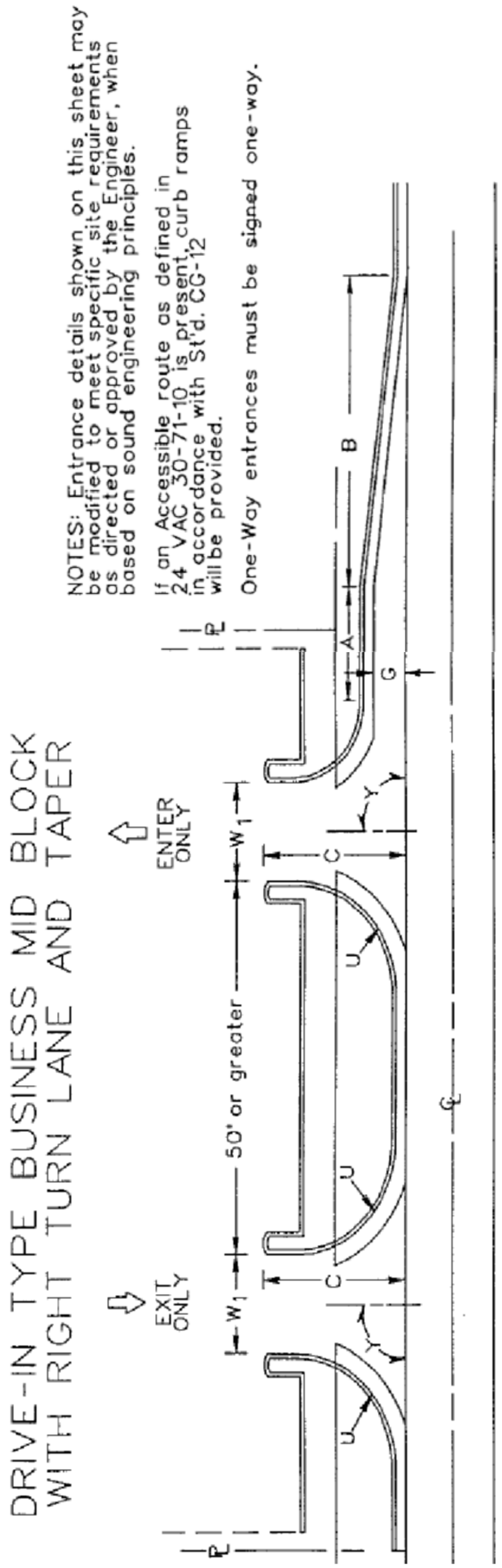
This section presents an exhibit to determine when to construct a right-turn lane, followed by parts from a figure that contains criteria for the design of elements related to a right-turn lane. An example of a driveway island design is also shown.



LEGEND

PHV - Peak Hour Volume (also Design Hourly Volume equivalent)

GUIDELINES FOR RIGHT TURN TREATMENT
(2-LANE HIGHWAY) VA *Appendix C*, p.C-32



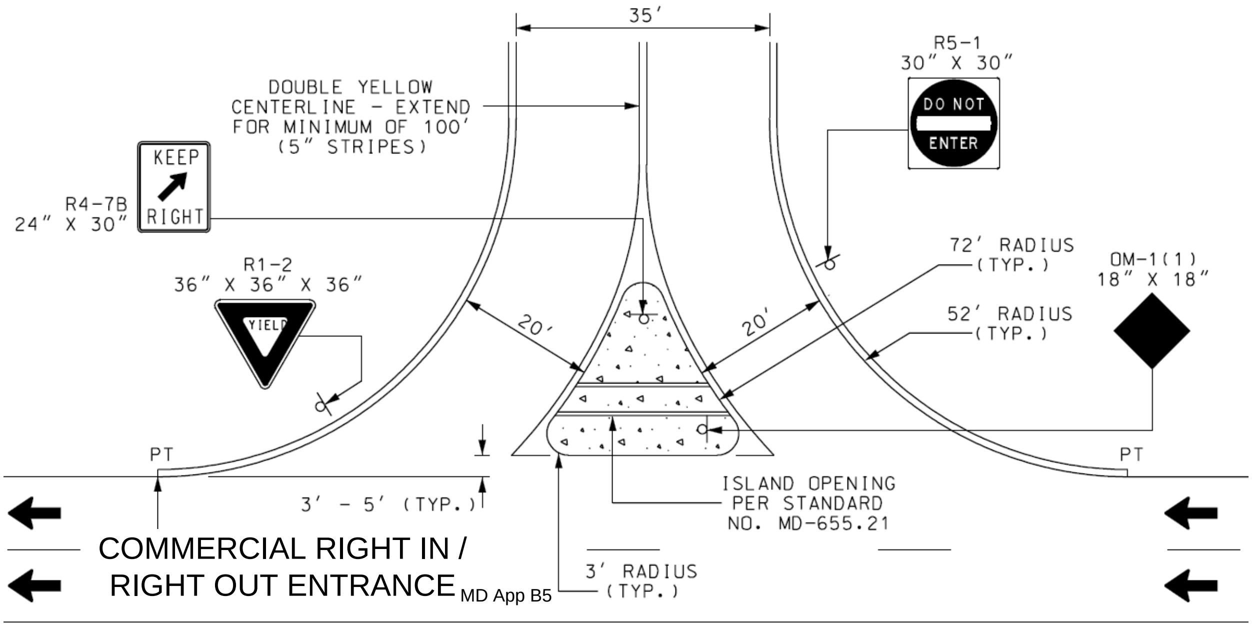
LETTER SYMBOL	DIMENSIONS
A	As determined by the Enginner
B	100' or greater
C	25' or greater. In developing areas where it is anticipated that the right turn lane will become a continuous thru lane in the future, an additional 12' is recommended.
G	12'
P	50' or greater (additional length will be required as directed by the Engineer if intersection is signalized or future signalization is anticipated.
U	12.5'-50'. The radii selected shall accomodate the anticipated type of vehicle usage. Larger radii should be considered by the Designer or may be required by the Engineer if larger vehicles are anticipated; however, in no case shall radius beless than 12.5'.
W	30'-40'
W_1	14'-20' for one-way traffic
Y	60° - 90°

Minimum distance from gasoline pump to R/W line for Service Station	
Pump Island to Pavement Edge	Distance
Parallel	12 ft.
1° to 45°	20 ft.
46° to 90°	30 ft.

STORAGE SPACE	
No. of Patron Service Points	Min. Length * of Lane Per Patron Service Point
1	200 ft.
2 or More	150 ft.

COMMERCIAL
ENTRANCE DESIGN
TO SERVE DRIVE-IN
TYPE BUSINESSES

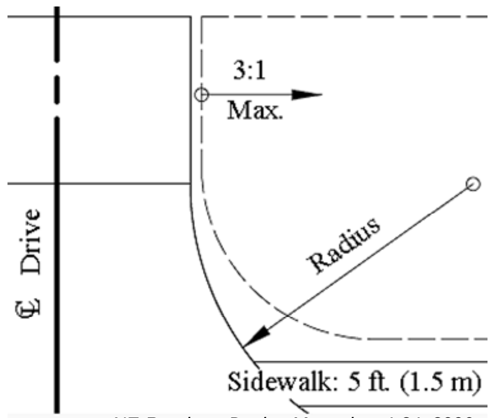
VA *Minimum Standards of Entrances to State Highways*, p. 31, 2003



COMMERCIAL RIGHT IN / RIGHT OUT ENTRANCE MD App B5

Examples Design Guidelines: Driveway Side Slope or Shoulder

The exhibits in this section are related to the design of the side slope or the edge shoulder of the driveway itself.



NE *Roadway Design Manual*, p. 4-34, 2006

STDS. FOR RESIDENTIAL AND COMMERCIAL DRIVES

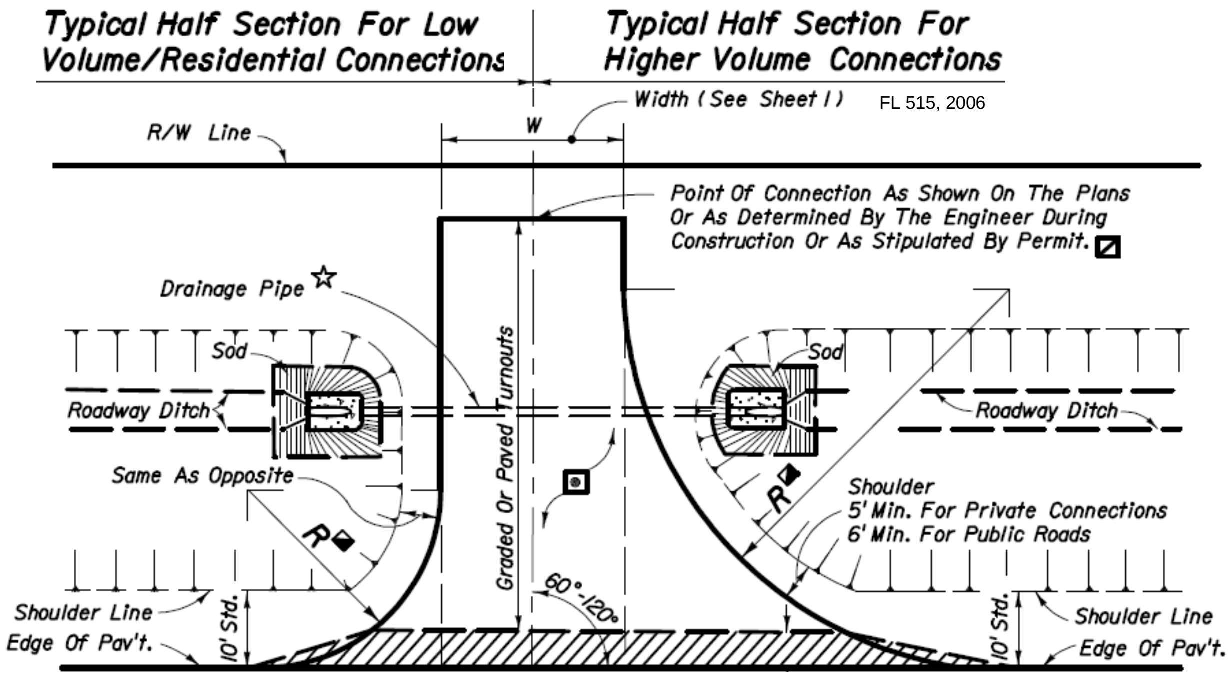
DRIVE SIDE SLOPES

VT B-71, 2005

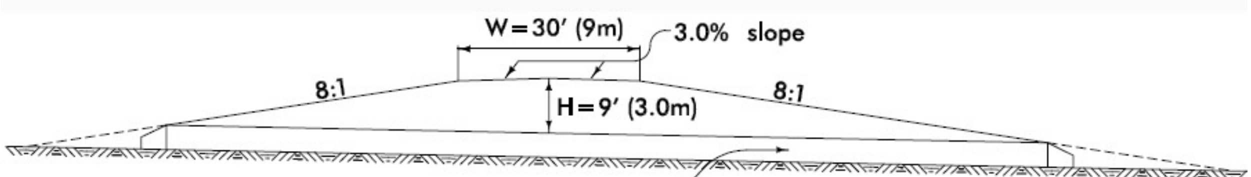
LOCATION OF SLOPE	SLOPE RATE
V > 40 MPH	1:6 OR FLATTER
URBAN AREAS, OR V ≤ 40 MPH	1:4 DESIRABLE 1:2 ALLOWABLE
OUTSIDE CLEAR ZONE	1:2 OR FLATTER

Transverse Slopes. Where the highway mainline intersects a driveway, a slope transverse to the mainline will be present. See Section 13-3.07. If impacted by a run-off-the-road vehicle, the angle of impact will likely be close to 90°. Even for relatively flat side slopes, this will result in vehicular vaulting; for steeper slopes the vehicle bumper may "catch" in the slope resulting in an abrupt stop and high occupant decelerations. For these reasons, transverse slopes should be as flat as practical. For design speeds greater than 45 mph, the slope should be 1:10 or flatter. For 45 mph or below, the slope should be 1:6 or flatter.

CT *Hwy. Des. Manual*, 11-8, 2003



This section covers the proper determination of pipe length and payment for entrance and safety dike pipe culverts. Typically, entrances or safety dikes with pipes will have foreslopes of 8:1. In cases where a steep ditch grade, 4% or more, is involved the designer may want to adjust the foreslopes.

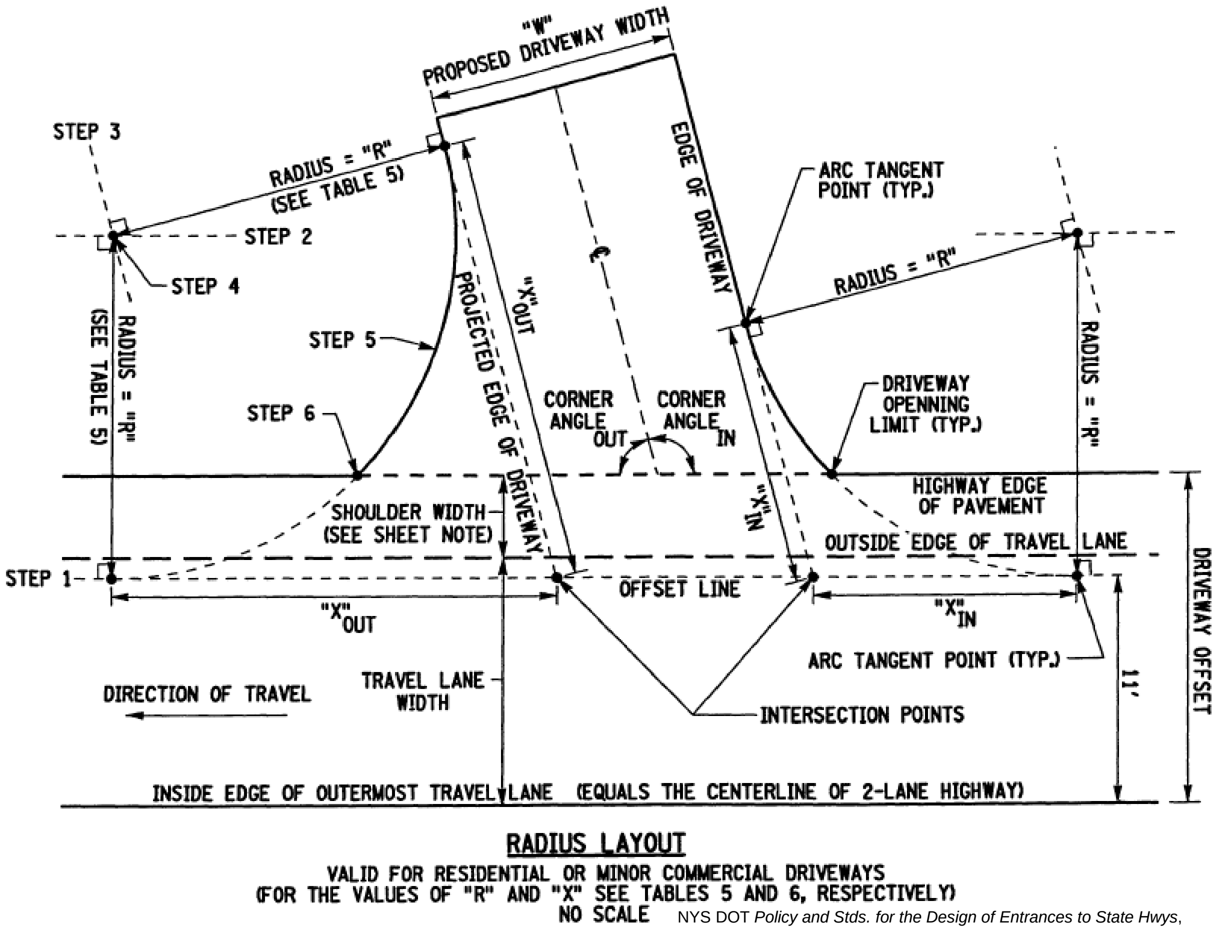


IA DOT *Design Manual*, Chp. 4B-1, Jan. 2004

Examples Design Guidelines: Aid for Skewed-Angle Layout

When the driveway intersects the roadway at a 90° angle, the geometric layout of the driveway and its accompanying the radius is a fairly simple task. However, when the driveway intersects the roadway at a skewed angle, a greater understanding of basic principles of geometry is needed to correctly layout the geometry.

An example of one state's design aid follows. It presents a step-by-step procedure to correctly locate the beginning and ending points of the intersection radius curve. Additional information in the source document includes a table of already-calculated dimensions.



NYS DOT *Policy and Stds. for the Design of Entrances to State Hwys*, Driveway Entrance Layout, Fig. 5A-4, 2003

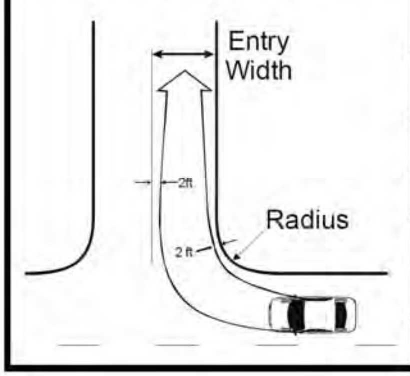
APPENDIX B

Survey of Current Practices: Additional Responses

The exhibits in this section are associated with and supplement the responses to survey questions 7, 8, 10, and 17.

7. Does your agency have any criteria (such as in a table) to establish a relationship **between driveway entry radius or entry angle/flare/taper dimensions and other features** such as driveway width, mainline roadway speed, etc.?

Exhibit 15



Radius or Flare (ft.)	Single Lane Width for Entry for Passenger Vehicles (ft.)
Typical flared driveway	22 ft (Pavement striping should be used if entry is this wide)
10 ft Radius	19 ft
15 ft Radius	17 ft
20 ft Radius	14 ft
25 ft Radius	14 ft
Over 25 ft Radius	12-14 ft

Fla. DOT, *Driveway Handbook*, p. 31, Mar. 2005

NYS DOT Fig. 5A-5, 2003

TABLE 10
DRIVEWAY OPENING "Y" (FT) VALUES FOR RADIUS METHOD - MINOR COMMERCIAL DRIVEWAYS (R = 33')

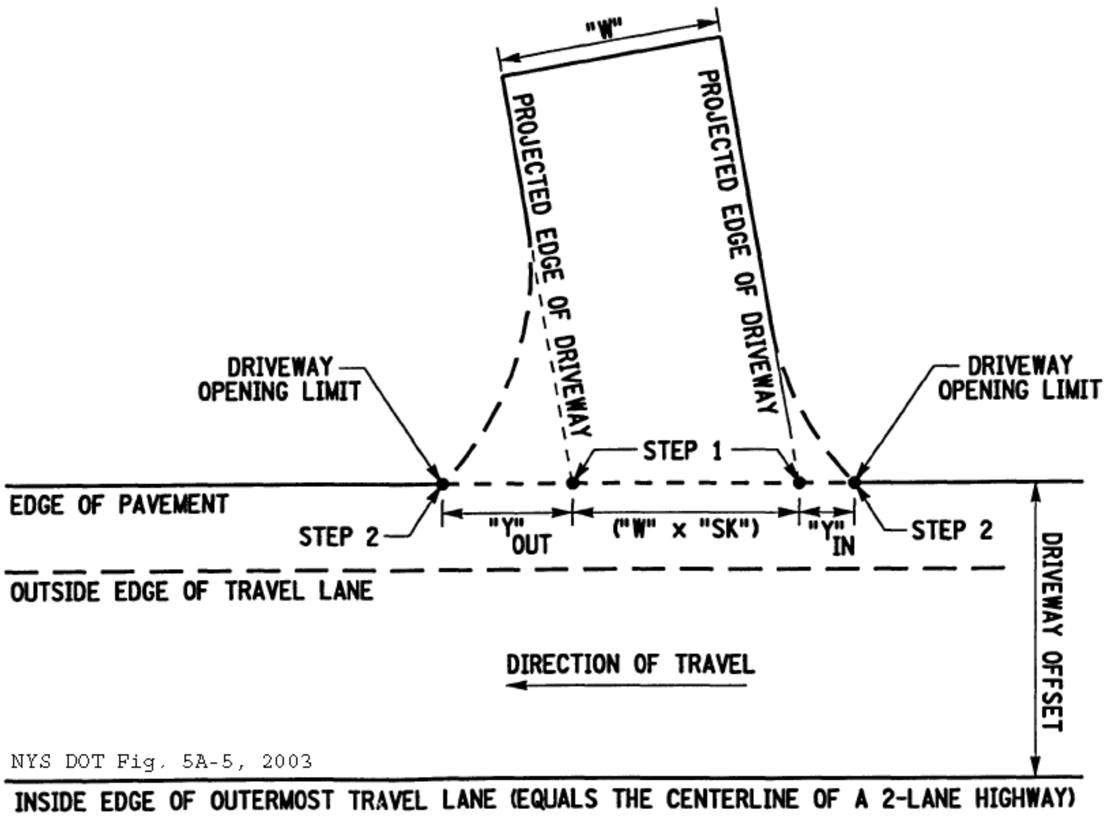
CORNER ANGLE	DRIVEWAY OFFSET FROM INSIDE EDGE OF TRAVEL LANE (OR OFFSET FROM OUTSIDE EDGE OF A 12' TRAVEL LANE)										
	12' (0')	13' (1')	14' (2')	15' (3')	16' (4')	17' (5')	18' (6')	19' (7')	20' (8')	21' (9')	22' (10')
60°	48.2	44.6	41.7	39.0	36.7	34.8	32.8	31.2	29.5	27.9	26.2
65°	43.3	39.4	36.7	34.1	32.2	30.2	28.2	26.6	24.9	23.6	22.3
70°	38.7	35.1	32.2	29.9	27.9	25.9	24.3	22.6	21.3	20.0	18.7
75°	34.8	31.2	28.5	26.2	24.3	22.6	21.0	19.4	18.0	16.7	15.7
80°	31.2	27.6	24.9	23.0	21.0	19.4	17.7	16.4	15.1	14.1	12.8
85°	27.9	24.6	22.0	20.0	18.0	16.7	15.1	13.8	12.8	11.5	10.5
90°	24.9	21.7	19.4	17.4	15.7	14.1	12.8	11.5	10.5	9.5	8.5
95°	22.3	19.0	16.7	14.8	13.5	11.8	10.5	9.5	8.5	7.5	6.9
100°	19.7	16.7	14.4	12.8	11.2	9.8	8.9	7.5	6.6	5.9	5.2
105°	17.7	14.8	12.5	10.8	9.2	8.2	6.9	5.9	5.2	4.6	3.9
110°	15.4	12.5	10.5	8.9	7.5	6.6	5.6	4.6	3.9	3.3	2.6
115°	13.5	10.8	8.9	7.2	5.9	4.9	4.3	3.3	2.6	2.3	1.6
120°	11.5	8.9	7.2	5.6	4.6	3.6	3.0	2.3	1.6	1.3	1.0

TABLE 13 - DRIVEWAY OPENING WIDTH CALCULATION							
DRIVEWAY OPENING WIDTH = $"Y"_{IN}$ + ("W" x "SK") + $"Y"_{OUT}$							
CORNER ANGLE	60°/120°	65°/115°	70°/110°	75°/105°	80°/100°	85°/95°	90°
SKEW FACTOR ("SK")	1.16	1.10	1.07	1.04	1.02	1.01	1.00

NYS DOT Fig. 5A-5, 2003

TABLE NOTE:
IF THE DRIVEWAY IS A ONE-WAY ENTRANCE OR EXIT, THEN "Y"(OUT) OR "Y"(IN), RESPECTIVELY, IS NOT INCLUDED IN THE EQUATION. ALTHOUGH FOR CURBED HIGHWAYS, ADDITIONAL DRIVEWAY OPENING WIDTH SHOULD BE ADDED TO ALLOW FOR A SMALL CORNER CURB RADIUS, TO ELIMINATE A SHARP CORNER BEND IN THE CURBLINE (THIS IS SAFER FOR SNOWPLOW OPERATIONS).

SAMPLE CALCULATION :
A 10′ WIDE RESIDENTIAL DRIVEWAY CONNECTING WITH A CORNER ANGLE OF 70° (THEREFORE RADIUS METHOD REQUIRED) TO A HIGHWAY WITH A 12′ WIDE TRAVEL LANE AND 4′ PAVED SHOULDER (= 16′ DRIVEWAY OFFSET) WOULD REQUIRE A DRIVEWAY OPENING WIDTH = $"Y"_{70°}$ + ("W" x "SK") + $"Y"_{110°}$ = 10.2 + (10 x 1.07) + 1.6 = 22.5′.



8. Does your agency have criteria (such as in a table) to determine when a driveway is allowed to **have more than 2 lanes**?

Response:

Section 550.80 Industrial-Commercial-Recreational High-Volume Traffic Generator Driveway Requirements

e) The following general requirements will pertain to these types of driveways.

1) Width of Drive. A driveway for these types of developments may have a maximum width of 35 feet when undivided or may consist of two 24-foot drives, one for entering and one for exiting traffic, divided by a median. The entrance to the development shall be designed to avoid backing up traffic on the highway so that traffic waiting to enter into the facility blocks through traffic. The number of lanes exiting from the development and turning in one direction shall not exceed the number of available traffic lanes on the highway in that direction. For example, if the exit is on a two-lane two-way pavement, no more than one lane will be allowed to exit at the same time in each direction.

Illinois *Administrative Code*, 92.I.f, Part 550

10. Are any **design vehicle** (such as P, SU) **characteristics** such as turning radius explicitly incorporated into your agency's typical driveway geometric design(s)?

CT Fig. 11-8A, 2003

Driveway Design Element		Driveway Type		
		Residential	Minor Commercial	Major Commercial
Design Vehicle		P	SU* (WB-50 can physically make turn)	WB-50*
Tolerance Encroachment by Design Vehicle Turning Into/Out of Driveway	Adjacent Lane on Through Road	None into opposing lanes of travel. Acceptable into lanes moving in same direction; however, consider providing a design so that there will be no encroachment.		
	In Driveway	Use all of driveway width if 1-way; no encroachment into driveway entrance or exit lane if 2-way, unless low-volume driveway.		
Width		Based on 1-way or 2-way operation; on selected design vehicle template; on encroachment criteria; and on assumed speed. (Note: Minimum residential driveway width = 10 ft. Maximum width is 30 ft.)		

Table 3-7 Driveway Radii

SC ARMS, p. 16, 1997

Design Vehicle			Minimum Radius	
	ft.	m	ft.	m
Single Unit Truck	SU	SU	40	12
Tractor Trailer	WB-40	WB-12	40	12
Tractor Trailer	WB-50	WB-15	50	15
Tractor Trailer	WB-62	WB-19	50	15

Residential	P
Farm	SU and Bus
Utility and Special Use	SU and Bus
Commercial	varies (SU, WB 40, WB 50, doubles)

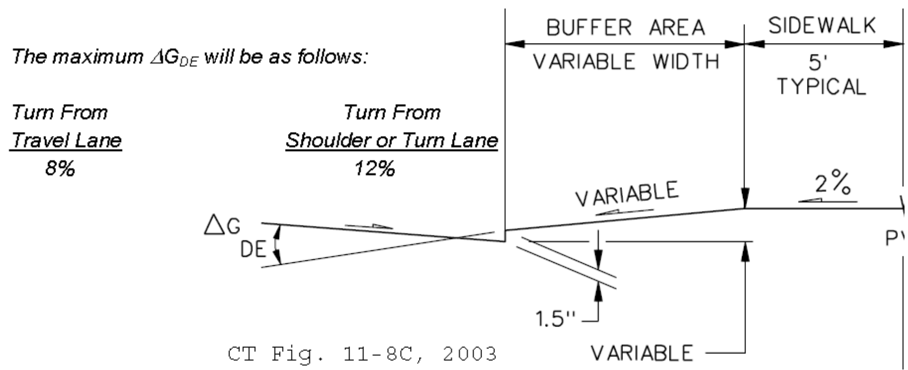
17. Does your agency have explicit warrants, maximum change-of-grade allowed, or design criteria for **driveway vertical curves**?

Grades on Driveway Proper		≤ 10% - 12%	≤ 5% - 8%	≤ 5% - 8%
Maximum Change in Grade Without Vertical Curve (ΔG)	Driveway Entrance	See Figures 11-8B, 11-8C and 11-8D		Designed like street intersection
	Driveway Proper	15%	6%	3%

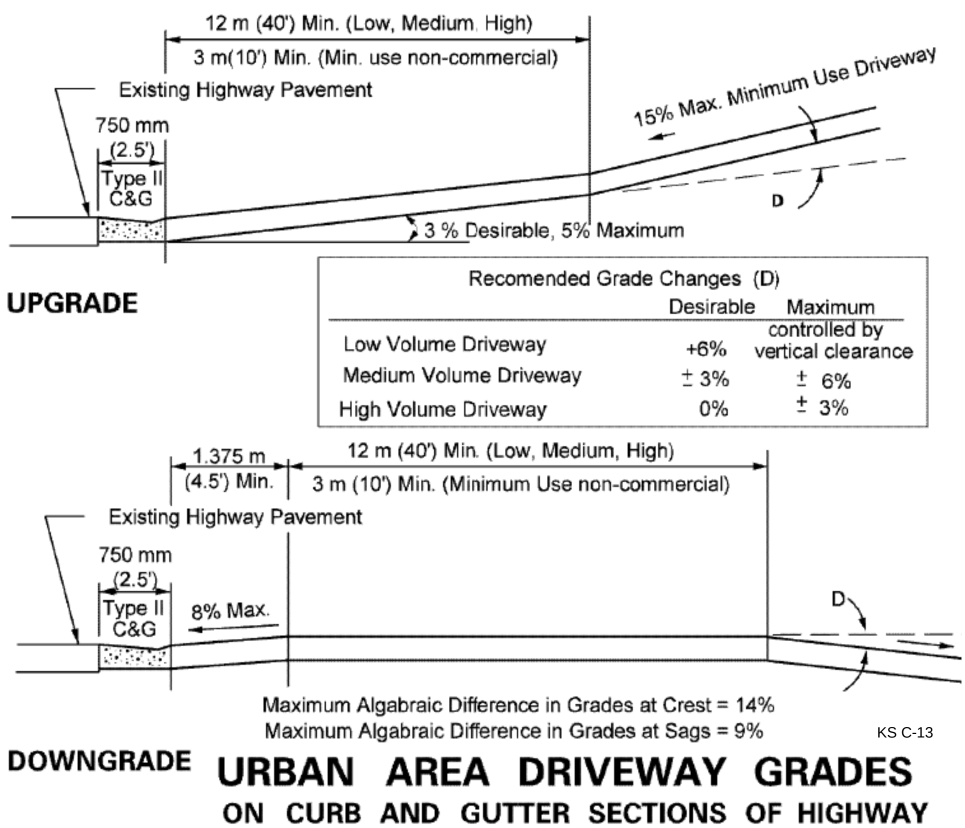
CT Fig. 11-8A, 2003

Minimum vertical curve radius: Sag, = 75 feet ; Crest, = 45 feet.

Minimum length of vertical curve = 10 feet.



CT Fig. 11-8C, 2003

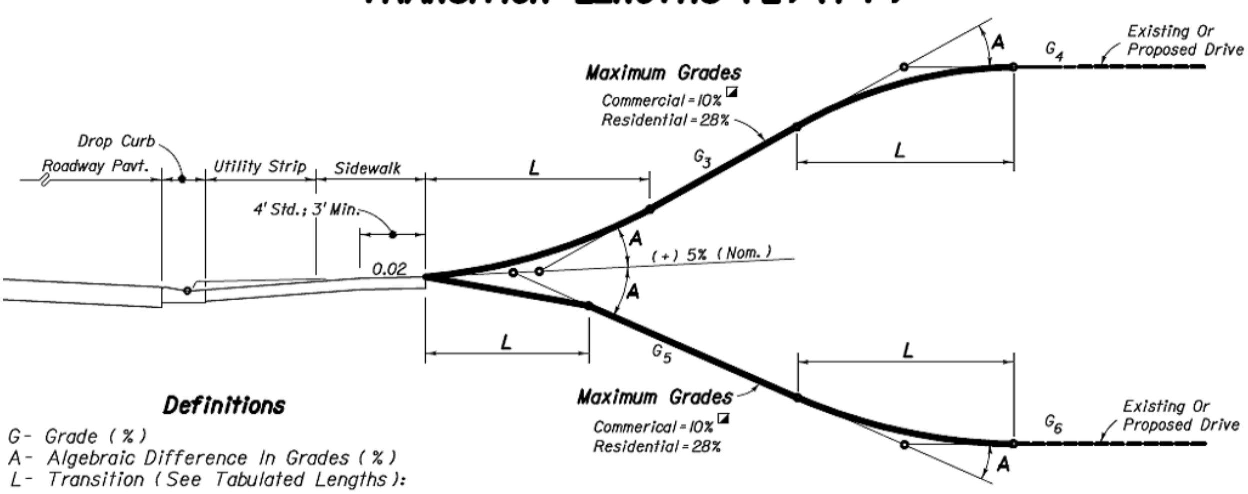


LENGTHS (L) (FT.) FL 515, 2006								
A	**CRESTS**				**SAGS**			
	STRAIGHT		**ROUNDED**		**STRAIGHT**		**ROUNDED**	
	Desirable	Minimum	Desirable	Minimum	Desirable	Minimum	Desirable	Minimum
6-13%	3	0	5	0	3	0	5	0
14%	3	0	10	0	3	0	10	0
15%	3	2.5	10	3	5	3	10	5
16%	5	3	10	4	6	4	10	6
17%	6	3.5	10	5	8	5	10	7
18%	6	4	10	6	9	6	10	8
19%	7	4.5	10	7	11	7	12	9
20%	8	5	11	8	12	8	13	10
21%	9	5.5	12	9	13	8.5	14	11
22%	10	6	13	10	14	9	16	12
23%	10	6.5	14	10.5	14	9.5	16	12.5
24%	11	7	15	11	15	10	17	13
25%	12	7.5	15	11.5	16	10.5	18	13.5
26%	12	8	16	12	17	11	18	14
27%	13	8.5	17	12.5	17	11.5	19	14.5
28%	14	9	17	13	18	12	20	15
29%	NA	NA	22	14	NA	NA	21	17
30-31%	NA	NA	23	15	NA	NA	22	18
32-33%	NA	NA	24	16	NA	NA	23	20
34-36%	NA	NA	26	17	NA	NA	25	21
37-38%	NA	NA	27	18	NA	NA	26	22
39-41%	NA	NA	29	19	NA	NA	28	24
42-43%	NA	NA	30	20	NA	NA	29	25
44-46%	NA	NA	32	21	NA	NA	31	26
47-48%	NA	NA	33	22	NA	NA	32	27
49-51%	NA	NA	34	23	NA	NA	34	28
52-54%	NA	NA	36	24	NA	NA	35	30
55-56%	NA	NA	37	25	NA	NA	36	31

Rounded: Either circular, parabolic or spline curvature. The plans or the Engineer may specify a particular type of curvature.

Desirable: Desirable minimum lengths.
Minimum: Absolute minimum lengths.
} Greater lengths than minimum and desirable are recommended where practical for flatter and smoother profile.

RECOMMENDED TURNOUT PROFILE TRANSITION LENGTHS (L) (FT)

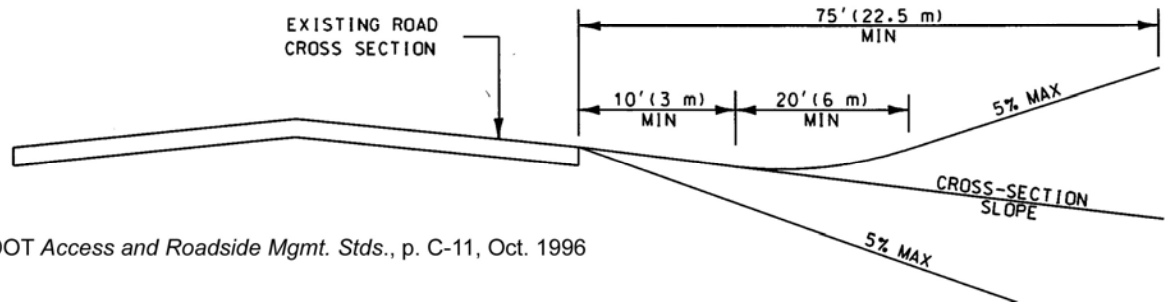


Definitions

G - Grade (%)
A - Algebraic Difference In Grades (%)
L - Transition (See Tabulated Lengths):
A ≤ 14% - Transition Not Required
A > 14% - Straight Or Rounded Transition Required

"Urban Turnout," FL 515, 2006

PROFILE OF STANDARD HIGH-VOLUME DRIVEWAY OR INTERSECTING STREET



SC DOT *Access and Roadside Mgmt. Stds.*, p. C-11, Oct. 1996

Table C-5. Length of Vertical Curve L (feet)
For a Change in Grade Between the Pavement Cross-Slope and the Driveway Apron Slope

Change in Grade, A				
	Crests		Sags	
	Des.	Min.	Des.	Min.
	ft (m)	ft (m)	ft (m)	ft (m)
4-5%	5 (1.5)	3 (0.9)	7 (2.1)	4 (1.2)
6-7%	6 (1.8)	4 (1.2)	8 (2.4)	5 (1.5)
8-10%	8 (2.4)	5 (1.5)	10 (3.0)	7 (2.1)

Rounded: Parabolic curvature. The plans may specify a particular type of curvature.

Des.: Desirable Minimum Length

Min.: Minimum Length

Where practical, greater lengths should be provided to achieve a flatter and smoother profile.

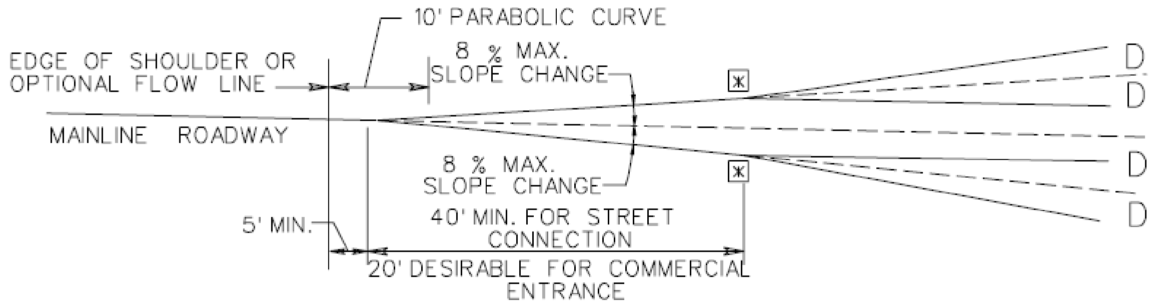
C-9 through C-11 illustrate typical driveway profiles.

TxDOT Roadway Design Manual, 2006

Table C-6. Typical Length of Vertical Curve, L,
For Change in Grade in Driveway Profile

TxDOT Roadway Design Manual, App. C, 2006

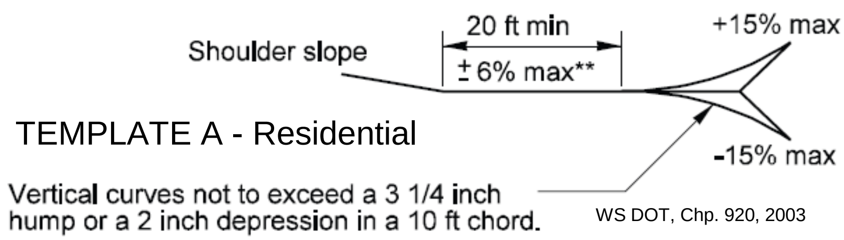
	Crest		**Sag**	
Change in Grade A	**Private Residential Driveways**	**Other Driveways**	**Private Residential Driveways**	Other Driveways
	ft (m)	ft (m)	ft (m)	ft (m)
4-5%	2 (0.6)	5 (1.5)	3 (0.9)	6 (1.8)
6-7%	3 (0.9)	5 (1.5)	5 (1.5)	7 (2.1)
8-10%	4 (1.2)	6 (1.8)	6 (1.8)	8 (2.4)

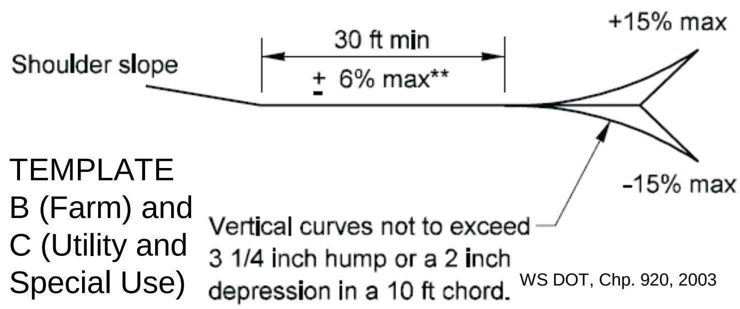


SECTION A - A

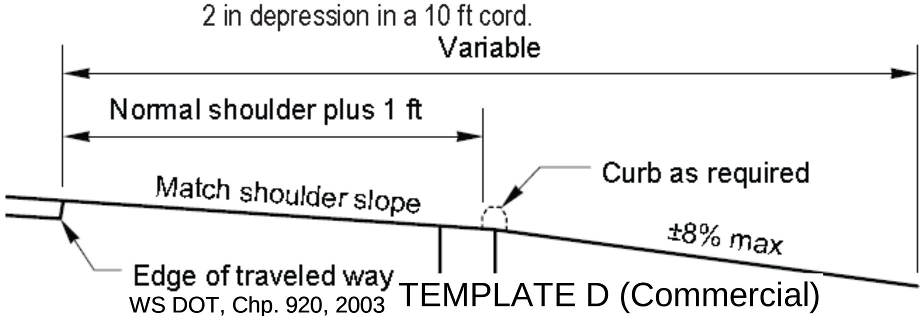
GUIDELINES FOR GRADE CHANGE D VDOT CG-11, 2001

ENTRANCE VOLUME	DESIRABLE	MAXIMUM
HIGH (MORE THAN 1500 VPD)	0 %	3 %
MEDIUM (500-1500 VPD)	≤ 3 %	6 %
LOW (LESS THAN 500 VPD)	≤ 6 %	8 %





(5) Vertical curves between the shoulder slope and the road approach grade not to exceed a 3¼ in hump or a 2 in depression in a 10 ft cord.



APPENDIX C

Additional Sources: Stakeholder Groups and Organizations

As the work on the initial tasks of this project proceeded, it became evident that it would be desirable to make contacts with organizations and groups that represent stakeholders (e.g., bicyclists, pedestrians, disabled pedestrians, public transit users) who may be affected by driveway designs and driveway traffic. The message to these organizations and groups began with a brief explanation of the research project, then continued with the following request for their input.

> If your organization would like to submit/suggest any of the following, then please contact me or forward the information to me by October 13, 2006.
>
> 1. submit any data, research findings, or other information that you think should be considered when driveway geometrics (elements such as the various physical dimensions, grade/slope, shape at the entry, use of islands, drainage) are designed
> 2. suggest measures that could be used to evaluate the performance of driveway designs or design elements, as related to safe and efficient travel by the various user groups
> 3. suggest aspects or issues related to driveway geometric design that need additional research, and the method(s) to study the issue(s)

This message was sent (usually via e-mail) to the following groups and organizations that the research team identified.

- AAA Foundation for Traffic Safety
- America Bikes
- American Council of the Blind
- American Public Transit Association
- Bikes Belong Coalition, Ltd.
- The League of American Bicyclists
- National Council on Disability
- National Safety Council
- The Partnership for a Walkable America (PWA)
- Transportation Research Board committees
  - ABE60 Accessible Transportation and Mobility Committee
  - ANF10 Pedestrian Committee
  - ANF20 Bicycle Transportation Committee
  - APO50 Bus Transit Systems Committee

U.S. Access Board

The contacts made with various groups and organizations generated 13 separate responses. Some of respondents were state DOT employees.

The content of these responses ranged from opinions about design nuances to proposed research activities. Some of the main issues from the comments are highlighted below.

1. Driveway opening width can be incorporated into a curbside transit-bus stop.
2. Drainage effects need to be considered when designing the vertical profile.
3. There is a need for more emphasis on who has the right-of-way at sidewalk/driveway crossings.
4. Suggested research topics.
    a. effectiveness of special pavement markings to indicate the presence of a bicycle path
    b. effectiveness of treatments to improve detection of the walking path for pedestrians with impaired sight
    c. effects of driveway-related speed differential (on the main roadway) on crash rates
    d. coordinating driveway geometry and roadside mailbox locations

The following excerpts present condensed and reformatted versions of the responses received.

#1 From:

I am the former (now retired) Director of the Office of Planning and Coordination for the Bureau of Transit Operations, New York City Dept. Transportation.

My only comment is to note that in New York City driveways can be incorporated into **bus stops**. The major requirement is that there must be a sufficiently long area on the sidewalk for safe passenger waiting between the curb cuts and the bus door opening positions. In other words, the fact that a driveway may at times be obstructed by portions of a bus stopped for a short time to pick up passengers should not be considered a fatal problem in bus stop placement. This may be a consideration where driveways are located close together in high density developments.

#2 From: [mailto: @bellevuewa.gov]

Hello, I work in the Traffic Engineering Division of the City of Bellevue Washington. …..

Also, one area we found to be of particular challenge … those situations where either the street or driveway beyond the apron has higher than average grades. For instance if a home is … lower than the grade of the sidewalk, it results in several problems including **drainage** related issues, if not properly designed. Water from the gutter can pass down over across the driveway apron and on to private property flooding the garage of the home. So, we would ask that you consider those areas extending beyond the driveway apron itself when developing recommended driveway standards. Perhaps alternative designs include special drainage elements such as French drains at the back of driveway or lips at the gutter/driveway seam. The transitions beyond the immediate driveway limits itself will be a key factor in good driveway design that works for all users.

#3 From: area person employed by transportation-related company

The City of Cambridge MA is considering applying blue paint to further delineate a **bicycle** path that runs parallel to a major roadway and has a number of driveway crossings that represent conflict points. This might be an opportunity to test the effects of paint and/or other marking strategies on driver behavior when entering/exiting driveways conflicting with bicycle traffic. The staff contact would be …

#4 From: BIKEFED@aol.com [mailto:BIKEFED@aol.com]

Thank you for the opportunity to comment at an early stage in this study.
I have only one comment to make at this time:

First and foremost, it must be stated, made clear, and maintained that in every case, a driveway will cross the pedestrian "element" (or space) in the right-of-way. At such place or point, the first priority, and primary design parameter, must ALWAYS be to provide for the needs of the pedestrian, including persons with disabilities. There should be no exceptions or variances to this requirement.

Thank you and good luck,
National Center for Bicycling & Walking

REPLY FROM GATTIS: I appreciate your taking time to respond. Can you convey more information related to your position? I'm not sure what is the best way for me to convey what I'm asking, so I am going to say this three different ways:

1. What are the justifications or reasons for your position?
2. What particulars led to your conclusion/position?
3. What factors or considerations can one cite to help support your position, with respect to the two groups you mentioned: pedestrians, and persons with disabilities?

Again, thank you -- looking forward to your response. Jim Gattis

From: ...@aol.com
Jim, Thanks for following up. …That said, to your questions:

The "logic" I am using to support my admonition is based, in part, on the UVC section noted below which establishes that drivers of vehicles crossing a sidewalk are required to yield to pedestrians and all other traffic on the sidewalk.

The "model." then, is the same as for a vehicle from a minor street crossing a major street: to yield to any traffic on the major street. Thus, in the sidewalk/driveway intersection, the sidewalk is the equivalent of the Major Street, or the primary way.

Further, the US Access Board and FHWA guidelines for sidewalks crossed by driveways make clear that the cross slope of the sidewalk shall take precedence over the slope of the driveway crossing the sidewalk. The maximum permitted cross slope for a sidewalk is 2% -- and at no time should any proposed driveway design be permitted that would result in anything greater.

In summary… the first priority must always be given to the sidewalk and the pedestrian, without compromise, just as is the case where a roadway crosses a railroad right-of-way. We don't "tilt" the rail bed nor stop the train to accommodate the motor vehicle.

National Center for Bicycling & Walking

#5 From: [mailto: @dot.state.wy.us]

1. submit any data, research findings, or other information that you think should be considered when driveway geometrics (elements such as the various physical dimensions, grade/slope, shape at the entry, use of islands, drainage) are designed

- radii, design vehicle, width, accel lane needed?, decel lane needed?, length of accel and/or decel, drainage away from main road and driveway, traffic speed on mainline, storage in driveway, minimum spacing between driveways and other roads/driveways.

2. suggest measures that could be used to evaluate the performance of driveway designs or design elements, as related to safe and efficient travel by the various user groups

- crashes, effect on upstream and downstream traffic such as slowing or erratic maneuvers, delay

3. suggest aspects or issues related to driveway geometric design that need additional research, and the method(s) to study the issue(s)

- the effects on mainline traffic of right in and right out accesses and the effects of u-turns at major intersections to handle right in and right out traffic. MOEs could be delay and crashes.

#6 From: [mailto:l @WSDOT.WA.GOV]

2. suggest measures that could be used to evaluate the performance of driveway designs or design elements, as related to safe and efficient travel by the various user groups

We should use the design aids like AutoTurn, etc. Vertical grades are a factor. Driveway spacing is a big issue. Turn restrictions is another issue. We should also look at sight distance.

3. suggest aspects or issues related to driveway geometric design that need additional research, and the method(s) to study the issue(s)

I suggest that you investigate 1) curb design options including incorporation of sidewalk and 2) access points (driveways) within the circulating roadway of a roundabout.

#7 From: person with US Forest Service [mailto: @fs.fed.us]

Here are my answers to your questions:

3. suggest aspects or issues related to driveway geometric design that need additional research, and the method(s) to study the issue(s)

In all honesty, I think it would be good to have a guideline on when to use and when not to use geometric design. On relatively flat ground, geometric design tends to result in roads that cost more to build, cost more to maintain, and are more impact on the environment than non-geometric design. If speed of travel isn't a consideration and ADT is less than 100, why waste money and mess up the environment?

NOTE: This response led to the observation about the potentially confusing **terminology** (i.e., using the term "driveway" when we actually are focusing on the area where the driveway, the sidewalk, and the roadway join).

#8 From:

Dear Dr. Gattis: I respond as a Friend of the TRB Pedestrian Committee.

I propose research on the **physical and visual aspects** of the border between a driveway and a perpendicular sidewalk, with particular reference to vision impaired pedestrians wayfinding with a long white cane or very limited vision. These pedestrians typically follow "shore lines" parallel to their direction of travel.

This shoreline often disappears completely where there is a wide driveway, for example, at an urban large parking lot or service station . . .

Research could **test alternative treatments** on a sample of vision impaired pedestrians. My organization would be glad to assist in this venture.

Council of Citizens with Low Vision International
REPLY FROM GATTIS: Thank you for this suggestion. Please provide me with more information . . .

\- - - - -

From:
Hi Jim. Thanks for asking!

I was thinking **only of the edge** of the pedestrian access route along the property line. . .

Yes, **visual contrast** refers to a very light and a very dark surface adjacent to each other. Dark asphalt in the parking lot or service station, would contrast with the light concrete of a sidewalk.

#9 From: @dot.state.fl.us

First, driveway aprons on which the **sidewalk crossing area is immediately adjacent to a dropped curb and gutter (i.e., adjacent to roadway) are prone to conflicts**. Drivers turning off the roadway into a commercial driveway are often concerned to exit it as quickly as possible to avoid rear-end hazards (as a pedestrian I have learned, when walking on right side of a street, to glance over my left shoulder for approaching traffic before stepping into such driveway crossings). Also, drivers preparing to enter the roadway typically stop in this area to wait for a gap to enter, blocking the sidewalk. A pedestrian usually has to hike around the back of the vehicle. A driveway on which the sidewalk crossing is set back a car length (or as nearly this length as practical) from the dropped curb reduces this problem, although it may not be as effective where a sidewalk is placed at back of curb, so that crossing a driveway in an area set back from the roadway involves an appreciable detour; if the crossing is out of my way, I am apt to take a short cut across the driveway.

Given evolving ADAAG requirements, set-back walkarounds are becoming more common. I don't know what the optimum setback is. As a crossing pedestrian, I don't want to be screened from the view of drivers approaching to turn into the driveway by sight-distance restrictions.

Second, **very wide drop-curb driveways** paved with asphalt are uncomfortable for pedestrians. Often, no specific crossing area is defined, and pedestrians are left to scurry like refugees across the trackless waste of exposed asphalt, with drivers entering and exiting at various points. Even modest strip-mall driveways are sometimes well over 100 feet wide, and driveways like this are still being built. A Lilliputian channelizing island to separate the entrance from the exit doesn't help pedestrians much. Driveways should be compact, the pedestrian crossing area should be defined, and any channelizing island should intersect the pedestrian crossing so as to **provide a useable refuge island**.

10 From: [mailto: @modot.mo.gov]

We are still trying to refine our grade change requirements in the "Vertical Geometrics (Driveway Grade Change)" section. We think we're pretty close to attaining an appropriate balance between the practical and theoretical. However, the **grade change** values are not fully field tested and we would appreciate any thoughts or comments.

Driveway performance is a combination of the elements normally discussed . . . However, we also see performance issues related to **pavement condition** and **pavement marking**. Driveways with poor pavement condition can cause a great deal of delay and speed differential. We have ongoing problems with striping, or more accurately the lack of striping, on commercial driveways. We don't require striping on commercial approaches unless they become signalized. Subsequently, we have a lot of three lane driveways that don't provide the needed delineation necessary for proper lane assignment. We have a few cities that try to overcome the lack of striping by using raised medians. However, we've found the medians often contribute more to delay than they remedy. In addition, we won't use them at all on routes posted at 50 mph or greater because of clear zone considerations. In conclusion, it would help us to have research on the operational/safety impacts of striping, pavement condition and perhaps even median placement on moderate volume commercial driveways.

11 From: pedestrian advocate

1) Most Important - Where pedestrian traffic exists (which would be most places), driveways should cross sidewalks, not the reverse (sidewalks cross driveways). **Sidewalks shall continue across the driveway at the sidewalk leve**l. The sidewalk crossing of the driveway shall be the same material as the sidewalk on either side of the driveway. In other words, the driveway should rise to the sidewalk level.

2) **Width** - Driveways should be as narrow as possible, allowing for the turning template of the design vehicle at a speed of 10 mph. Single family residential driveways should be no more than the width needed for one vehicle (regardless of the driveway width behind the sidewalk) entering or exiting (15-20 ft or so). Driveways shall at the maximum, allow for one vehicle in each direction. The area on either side of the driveway shall be designed to discourage vehicle access by **using a curb or other barrier** to constrain vehicles to the driveway area only.

… seek to protect pedestrians by reducing the turning speed into the driveways, reducing the width of driveways, and giving drivers the visual cue of turning into and crossing a pedestrian pathway. Likewise, reducing vehicle entry speeds creates more awareness of bicycle traffic in the roadway.

12 From: @Access-Board.gov]

I would certainly second …. observations about crossing driveways … and the desirability of a **tactile sidewalk edge** at such locations.

Additionally, we would note the importance of limiting walkway **cross slope** to 2% maximum and using geometric design features such as **tight curb radii** and **narrow openings** to limit driver turning speed. In general, we would favor setback sidewalks and sloped driveway aprons over curb-attached sidewalks that require the pedestrian route to be ramped down to the driveway elevation. We would also recommend that walkway surfaces continue across driveways and that aprons and driveways have a **visual contrast** with the walkway.

---

13 From: [mailto: @mobilecounty.net]

Issue 1: … the **mailbox**. … for non-curb roadways, typically a rural environment (grass shoulders). Mail carriers and the owners driving next to the driveway to get to the mailbox create a rut or washed-out area adjacent to the driveway. This can become a serious hazard for the driving public, edge of pavement drop-off. Many locations in our county allow the placement of mailboxes on high speed facilities (45 - 55 mph).

A possible solution would be to pave an area adjacent to the driveway (a paved shoulder), however, some mail carriers tend to drive partially along the shoulder from mailbox to box (creating a long rut).

Issue 2: … tends to minimize the **length of pipe** under the driveway (again a rural open-ditch section). The area adjacent to the pavement of the driveway, if the pipe is large, is a very steep slope. If the owner has a trailer or something similar in length, dropping off the edge of pavement occurs.

Again a maintenance issue, but rutting and erosion occurs, making condition worse and slowing the driver to a very low speed to negotiate. Even if a sloped-paved headwall is in place and the pipe size is large, this vertical drop tends to slow the driver.

??? How much separation between the two would be a good distance? I've seen 2-4 feet used.

APPENDIX D

Additional Sources: Automobile Dimensions

It has long been recognized that if the driveway vertical profile changes too abruptly, then the undersides of some vehicles are more likely to drag or hangup on the driveway surface. A comprehensive database of pertinent vehicle dimensions would need to be available before attempting to examine and define limiting driveway profile attributes. A number of publications list overall vehicle and wheelbase length, such as described in the following excerpt.

> Competing sites are implementing similar features. CarsDirect.com, for instance, has had a comparison function for two years and allows unlimited numbers of vehicles to be compared…. In addition to pricing information, the new Nadaguides.com comparison tool provides consumers with a comprehensive chart of detailed information for each vehicle, including power train data (EPA fuel economy; cruising range; engine type and displacement; fuel system type; transmission type and gear ratios); dimensions (passenger capacity; head, leg, shoulder and hip room statistics; length, height, overhang, ground clearance and cargo room information); and chassis data (axel weight, capacity and ratio; curb weight; option weight; hitch information; wheel and tire information; steering ratio; braking and fuel tank data).
>
> http://www.internetretailer.com/dailyNews.asp?id=12945 , Nov. 2006.

However, a visit to the site did not produce some of the data categories, such as overhang, indicated in the reviewer's article. The following information for a 2006 Buick Lucerne four-door model serves as an example.

<u>Exterior Specifications</u>
Turning Diameter - Curb to Curb (ft) 42.2
Turning Diameter - Wall to Wall (ft) - TBD -
Wheelbase (in) 115.6
Length, Overall (in) 203.2
Width, Max w/o mirrors (in) 73.8
Height, Overall (in) 58.0
Tread Width, Front (in) 63.0
Tread Width, Rear (in) 62.5
Min Ground Clearance (in) - TBD -

* http://www.nadaguides.com/default.aspx?LI=1-20-37-5060-654-620-50255&l=1&w=20&p=37&f=5061&m=1031&d=15858&y=2006&vt=new&s=279792&z=72701 Jan., 2007

The challenge lies in finding current overhang and ground clearance dimensions. Numerous leads were pursued in an attempt to identify a source for the specific vehicle dimensions needed to determine the limits of acceptable change in driveway vertical profile.

Through 1994, the American Automobile Manufacturers Association (AAMA) published "Vehicle Dimensions". For many Chrysler, Ford, and General Motors automobile models, this publication included a detailed list of dimensions (see following list) and the resulting limits of approach, ramp breakover, and departure angles.

Exterior Length Dimensions

L101 - Wheelbase (WB)
L103 - Vehicle length
L104 - Overhang, front
L105 - Overhang, rear

Exterior Height Dimensions

H102 - Bottom of front bumper to ground
H104 - Bottom of the rear bumper to ground
H106 - Angle of approach (The angle measured between a line tangent to the front tire static loaded radius arc and the initial point of structural interference forward of the front tire to ground.)
H107 - Angle of departure (The angle measured between a line tangent to the rear tire static loaded radius arc and the initial point of structural interference forward of the rear tire to ground.)
H147 - Ramp breakover angle (The angle measured between two lines tangent to the front and rear tire static loaded radius and intersecting at a point on the underside of the vehicle which defines the largest ramp over which the vehicle can roll.)
H153 - Rear axle differential to ground
H156 - Minimum running ground clearance (The minimum dimension measured from the sprung vehicle to ground.)

source: "Vehicle Dimensions", 1994 model year, American Automobile Manufacturers Association

An online search did not identify any current links to this organization. The www.aama.com link led to AMA Laboratories, which from its webpage appears to perform food and drug tests. One link (bea.gov/bea/dn/gap_hist.xls) led to a document which included automobile production figures, and among its sources included the AAMA through November, 1998, and other sources for figures after that date.

An online search, using keyword combinations such as "dimensions overhang clearance automobile OR vehicle" as did produce promising links to data from Australia and New Zealand, but not the United States.

While he was still the project coordinator, the research team asked Dr. Diewald if anyone at NCHRP knew of contacts that would lead to this information. In early September, he responded "I didn't have much luck asking around at TRB", but he did suggest contacting two people who were formerly employed at NHTSA. Attempts to contact them were unsuccessful (unable to find a phone number for one, and the other did not return telephone calls).

In an early-January conversation, Roger Bligh, a leading vehicle-crash tester with Texas Transportation Institute, confirmed that AAMA no longer existed. He offered that Expert Auto Stats (a source of vehicle information for crash reconstruction for trial lawyers) might sell this information on a per vehicle basis. He said that for a recent research project focused on light trucks, he encountered difficulty acquiring this type [e.g., overhang and clearance] of information, and had to "go make measurements in parking lots."

Later, attempts were made to contact (via e-mail) other potential sources of this information. The message inquired about a "database that includes front overhang (front bumper to front axle), wheelbase, rear overhang, and front/middle/rear ground clearance dimensions for a wide variety of passenger cars, pickup trucks, vans, etc." The following list (Exhibit B) identifies the organization contacted and, if they responded via e-mail (some responded on the telephone), their response.

To date, only one of the attempts resulted in either identifying a source of or acquiring this information. Information for Daimler-Chrysler vehicles was found; as an example, the dimensions listed for a 2006 Chrysler Crossfire follow.

EXTERIOR DIMENSIONS

Turning Diameter (curb-to-curb) - Turning Right [ft]	32.2
Overhang - Front [in]	32.3
Turning Diameter (curb-to-curb) - Turning Left [ft]	32.2
Overall Height	51.5
Overhang - Rear [in]	32.9
Wheelbase [in]	94.5
Overall Length [in]	159.8
Ground Clearance	4.9
Track - Front [in]	58.8
Track - Rear [in]	59.1
Overall Width [in]	69.5

from: http://www-5.chrysler.com/vehsuite/VehicleCompare.jsp , accessed Jan. 26, 2007

Automotive News	Automotive News: not contacted
Edmunds	Edmunds: reference number for your inquiry is '061130-000009'
Insurance Institute for Highway Safety (IIHS)	IIHS: no response
J. D. Power & Assoc.	J.D. Power: Thank you for contacting J.D. Power and Associates. Unfortunately, we do not have any information regarding overhang of the of car bumpers from the axel. I also am not aware of any companies that would have that information available. I am sorry that I cannot be of more help.
National Automobile Dealers Association (NADA)	NADA: no response
Society of Automotive Engineers (SAE)	SAE: responded with the results of a keyword search of their database; the links did not lead to the needed information
Wards Yearbook	Wards Yearbook: not contacted
Daimler-Chrysler	Daimler-Chrysler: -Sent: Friday, January 26, 2007 3:16 AM Excuse our late response to your email. Please look at our brands' homepage, where the vehicles data is described, … links on our main website www.daimlerchrysler.com. best regards, -
Ford Motor Co	Ford: … data such as you have requested is not maintained by the Customer Relationship Center. However, you may be able to obtain an answer to your inquiry by contacting the Henry Ford Museum… contains a research facility that is able to assist the public in determining certain historical facts. The Museum does charge a service fee for such inquiries, relative to the amount of research required.
General Motors	GM: was not able to locate a "general inquiry" category to on their website
Honda	Honda: -- responded on telephone; information not available
Toyota	Toyota: We apologize; the information you have requested is not available from Toyota.

EXHIBIT D-1 Record of search for certain vehicle dimension information

APPENDIX E
Additional Sources: Examination of Crash Data

To have a preliminary, broad understanding of the magnitude of the damage and injury that occur under the current state of practice, insight that could be derived from readily available crash data was considered.

SUMMARY TOTALS FROM A STATE DATABASE

The Arkansas crash data for 2005 were searched. From the entire database, the crashes coded as having involved a non-motorist (other than motor vehicle driver or passenger) were found, and those crashes with “relation to junction” coded as “driveway” were extracted. Within that driveway set, the non-motorist crashes were queried. Exhibit C presents relevant totals.

EXHIBIT C Crash data

	Number of crashes 2005
Relation to junction = driveway, and involving a non-motorist	98
Involving a non-motorist	722
Relation to junction = driveway	9,457
Total	69,516

Among all of the crashes in 2005, 0.9% were fatal and 3.2% had significant injury (also known as “injury A”, or code “2” on a 1 to 5 scale). Within the subset of crashes at driveways involving non-motorists, 3.1% were fatal and 11.2% recorded a significant injury. A non-motorist was involved in 1.0% of all crashes, and in 1.0% of driveway crashes.

Note that as a relatively rural state with a low population, pedestrian exposure at driveways in Arkansas may be less than average. In 2005, the Arkansas pedestrian fatality per 100,000 population rate was 1.05, while the value for the United States was 1.65 (NHTSA, “Traffic Safety Facts: Pedestrians,” DOT HS 810 624, 2005).

TOTALS FROM URBAN DATABASES

Although not a part of the NCHRP research project, the findings from analysis of crash data from two different urban databases may be of interest.

Eck has reviewed the police crash reports for all reported pedestrian crashes in Morgantown, WV for calendar years 2002, 2003 and 2004. Morgantown is a rapidly growing university city with approximately 50,000 permanent residents. During these three years, there were 72 reported pedestrian crashes; over one-half of these (40) occurred in 2004. Overall, 49% of the crashes occurred during hours of darkness and 75% occurred on dry pavement.

Eight of the 72 pedestrian crashes (11%) were driveway-related. Although the number of crashes is small, the detail provided by the police reports provides insight into the nature of the crashes and the circumstances surrounding them. For these driveways crashes, 25% occurred at night and 25% occurred on wet pavement. All crashes involved vehicles leaving a driveway. One-half of the crashes occurred at commercial driveways; three crashes occurred at driveways associated with parking facilities, and one occurred at a residential driveway (driver backed into a wheelchair user traveling along the street since there were no sidewalks in the residential area).

One-half of the involved vehicles were turning left. In four of the crashes, pedestrians crossing the driveway were struck by turning vehicles. Three crashes involved pedestrians crossing at mid-block who were struck by turning vehicles. One of these involved a pedestrian crossing a multi-lane arterial roadway. The pedestrian was in a two-way left-turn lane waiting to cross the other half of the arterial and was struck by a vehicle turning left from the driveway. The other two crashes occurred on two-lane, two-way streets.

An undergraduate student's honors thesis will report findings from the reports of the more than 2,000 crashes in the city of Springdale, Arkansas (population about 60,000) in 2006. The street network, land development, transportation mode choices, and overall look of this city are all typical of the relatively low-density, automobile-dominated cities found in much of the United States. Preliminary totals indicate that of the approximately 2,500 reported crashes during 2006, about 10% of these had driveway involvement.

The student began the data collection process by examining the codes, narrative, and drawing on each crash report. For the subset of those crashes related to driveways, the student is coding information from the crash report into a spreadsheet. During the subsequent analysis, it is anticipated that the student will attempt to make observations about the nature of the driveway-related crashes. In addition, observations about the difference between the number of crashes coded in the city database as driveway-related and the number of crashes determined to be driveway-related by the student will be noted. (A paper based on this work, #08-0710 by Rawlings and Gattis, is on the 2008 TRB annual meeting CD.)

APPENDIX F
Profiles of Driveways with Scrape Marks

< this is the side toward PRIVATE PROPERTY

Address + Street name: 5206 Balcones Dr
Driveway is in this city, state: Austin, TX
Land use type: Highland Park Bap. Church (S) exit drive

Land use abbreviations:
apt = apartment com = commercial
SF res = single-family residential

This form is set up for you to face **toward** oncoming vehicles on the through street.

Name : Gattis
Date measured : July 28, 2007

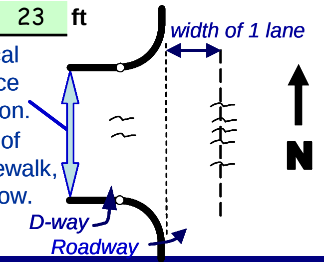
Set the horizontal position of the high or low point 0.0 here ↓

☐ Crest   Sag ☒

this is the side toward the ROADWAY >

D-way width: 23 **ft**

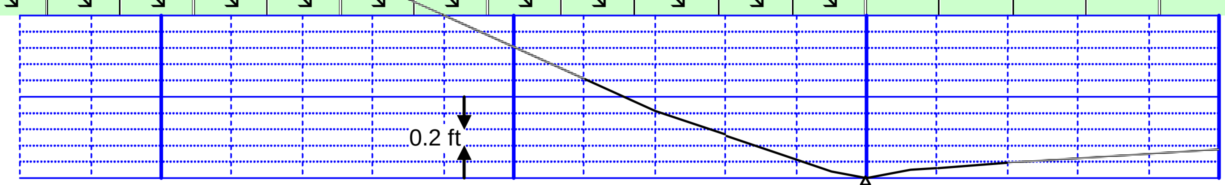
Measure the typical width of the surface available to drive on. Draw the location of gouge marks, sidewalk, islands, and N arrow.



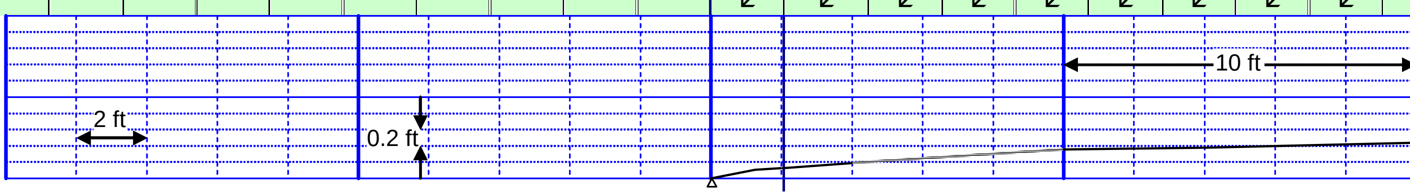
Label which side of the d-way: e.g., "south edge" ↓

① ENTER the % grade for the 2 ft or other increment; ② draw arrow to indicate slope; ③ draw the profile w/ scrape marks located.

			18 - 20 ft	16 - 18 ft	14 - 16 ft	12 - 14 ft	10 - 12 ft	8 - 10 ft	6 - 8 ft	4 - 6 ft	2 - 4 ft									< the 2 ft. increments
						< light scrape		16 to 8 ft >							< scrape 4 to 10 ft >					
since more marks were at dway CL, took only 1 profile, @ CL	24-22	22-20	20-18	18-16	16-14	14-12	12-10	10-8	8-6	6-4	4-2	2-1	1-0	< gutter line						
	-9.8	-16.0	-19.6	-21.6	-19.5	-19.3	-19.7	-19.7	-19.7	**-15.3**	**-15.2**	**-15.1**	**-7.5**							< %
	-0.196	-0.320	-0.392	-0.432	-0.390	-0.386	-0.394	-0.394	-0.394	-0.306	-0.304	-0.151	-0.075							
	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘							<downhill arrow



this is street-side								gutter line >		0-1.25	1.25-2	2-4								
										8.3	2.0	3.6	**2.9**	2.8	2.8	0.5	0.7	1.0	1.3	1.2	< %
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.104	0.015	0.072	0.058	0.056	0.056	0.010	0.014	0.020	0.026	0.024
										0.10	0.12	0.19	0.25	0.30	0.36	0.37	0.38	0.40	0.43	
										↙	↙	↙	↙	↙	↙	↙	↙	↙	↙	↙	<downhill arrow



-13.9%   2.9%
16.8% sag

< this is the side toward PRIVATE PROPERTY

Address + Street name: S. 1st north of Wm. Cannon
Driveway is in this city, state: Austin, TX
Land use type: com - small shopping center, HEB

Land use abbreviations:
apt = apartment   com = commercial
SF res = single-family residential

This form is set up for you to face **toward** oncoming vehicles on the through street.

Name : Gattis
Date measured : Sep. 17, 2007

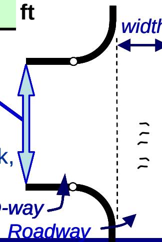
Set the horizontal position of the high or low point 0.0 here ↓

☐ Crest   Sag ☒

this is the side toward the ROADWAY >

D-way width: 30 **ft**

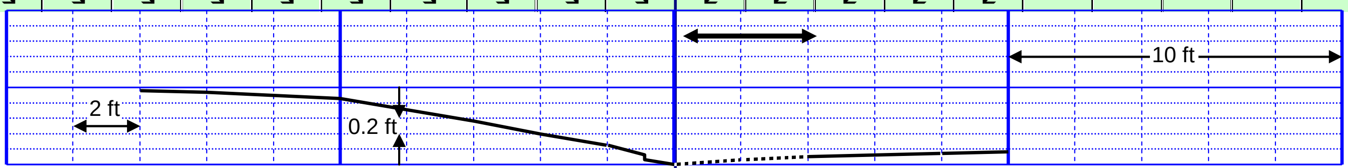
Measure the typical width of the surface available to drive on. Draw the location of gouge marks, sidewalk, islands, and N arrow.



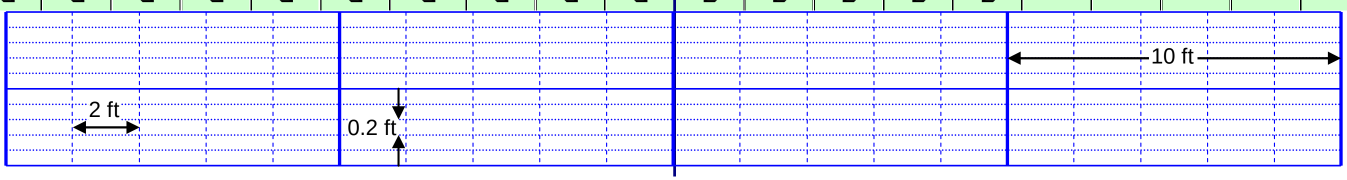
Label which side of the d-way: e.g., "south edge" ↓

① **ENTER the % grade for the 2 ft or other increment; ② draw arrow to indicate slope; ③ draw the profile w/ scrape marks located.**

											0 - 2 ft	2 - 4 ft	4 - 6 ft	6 - 8 ft	8 - 10 ft	10 - 12 ft	12 - 14 ft	14 - 16 ft	16 - 18 ft	18 - 20 ft	< the 2 ft. increments
											scrape	scrape									
	16-14	14-12	12-10	10-8	8-6	6-4	4-2	2-0.9	lip	0.9-0											
	-1.5	-2.4	-2.1	-7.3	-7.4	-7.8	-6.8	-6.6			2.8	1.8	1.4	0.8	1.2						< %
	-0.030	-0.048	-0.042	-0.146	-0.148	-0.156	-0.136	-0.073	0.125		0.056	0.036	0.028	0.016	0.024						
	0.91	0.88	0.84	0.79	0.65	0.50	0.34	0.21	0.14	0.01	0.06	0.09	0.12	0.14	0.16						
center	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘	↙	↙	↙	↙	↙						<downhill arrow



	16-14	14-12	12-10	10-8	8-6	6-4	4-2	2-0.9	lip	0.9-0											
	-1.1	-1.7	-1.3	-7.0	-7.9	-8.2	-8.7	-8.2			3.6	1.9	1.3	0.9	0.9						< %
	-0.022	-0.034	-0.026	-0.140	-0.158	-0.164	-0.174	-0.090	-0.125		0.072	0.038	0.026	0.018	0.018	0.000	0.000	0.000	0.000	0.000	
	0.94	0.92	0.88	0.86	0.72	0.56	0.39	0.22	0.13	0.01	0.07	0.11	0.14	0.15	0.17						
north edge	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘	↙	↙	↙	↙	↙						<downhill arrow



6	0.9	0.0	4
0.500	0.135	0.000	0.092

-7.1%   2.3%

9.4% sag

< this is the side toward PRIVATE PROPERTY

Address + Street name: 3339 Hancock
Driveway is in this city, state: Austin, TX
Land use type: com - Russells Bakery

Land use abbreviations:
apt = apartment   com = commercial
SF res = single-family residential

This form is set up for you to face **toward** oncoming vehicles on the through street.

Name : Gattis
Date measured : July 28, 2007

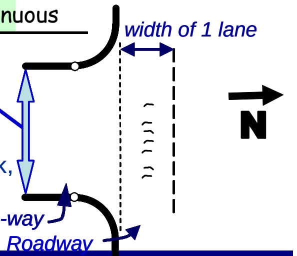
Set the horizontal position of the high or low point 0.0 here ↓

☐ Crest   Sag ☒

this is the side toward the ROADWAY >

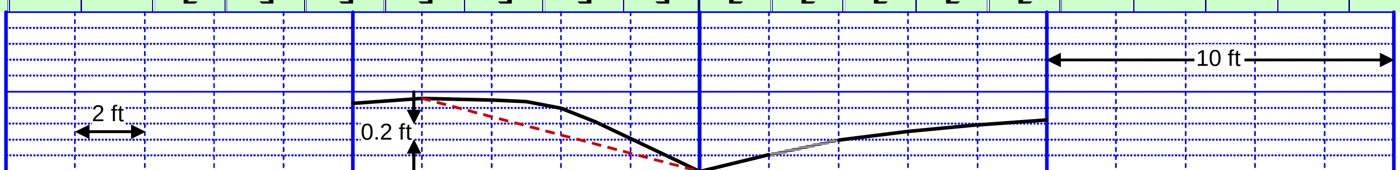
D-way width: continuous

Measure the typical width of the surface available to drive on.
Draw the location of gouge marks, sidewalk, islands, and N arrow.

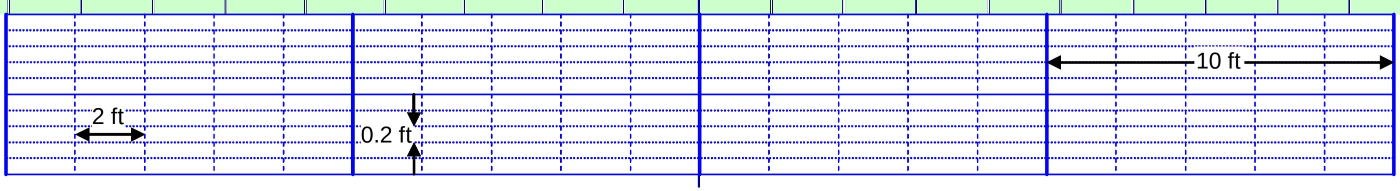


Label which side of the d way: e.g., "south edge" ↓	18 - 20 ft	16 - 18 ft	14 - 16 ft	12 - 14 ft	10 - 12 ft	8 - 10 ft	6 - 8 ft	4 - 6 ft	2 - 4 ft	0 - 2 ft	0 - 2 ft	2 - 4 ft	4 - 6 ft	6 - 8 ft	8 - 10 ft	10 - 12 ft	12 - 14 ft	14 - 16 ft	16 - 18 ft	18 - 20 ft	< the 2 ft. increments
												scrape									
Dway is continuous. Only 1 profile.				10-8	8-6	6-5	5-4	4-3	3-2	2-0											
				3.3	-0.2	-1.5	-7.4	-16.8	-21.7	-20.5	**10.3**	**9.2**	5.3	4.0	2.5						< %
	0.000	0.000	0.000	0.066	-0.004	-0.015	-0.074	-0.168	-0.217	-0.410	0.206	0.184	0.106	0.080	0.050	0.000	0.000	0.000	0.000	0.000	
					0.89	0.88	0.87	0.80	0.63	0.41	0.21	0.39	0.50	0.58	0.63						
				↙	↘	↘	↘	↘	↘	↘	↙	↙	↙	↙	↙						<downhill arrow

① ENTER the % grade for the 2 ft or other increment; ② draw arrow to indicate slope; ③ draw the profile w/ scrape marks located.



	18 - 20 ft	16 - 18 ft	14 - 16 ft	12 - 14 ft	10 - 12 ft	8 - 10 ft	6 - 8 ft	4 - 6 ft	2 - 4 ft	0 - 2 ft	0 - 2 ft	2 - 4 ft	4 - 6 ft	6 - 8 ft	8 - 10 ft	10 - 12 ft	12 - 14 ft	14 - 16 ft	16 - 18 ft	18 - 20 ft	
																					< %
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
																					<downhill arrow



effective grade = -11.5%   9.8%

21.3% sag

< this is the side toward PRIVATE PROPERTY

Address + Street name: 1021 W. Wm. Cannon
Driveway is in this city, state: Austin, TX
Land use type: com car wash - Genie

Land use abbreviations:
apt = apartment com = commercial
SF res = single-family residential

This form is set up for you to face **toward** oncoming vehicles on the through street.

Name : Gattis
Date measured : Jan 7, 2008

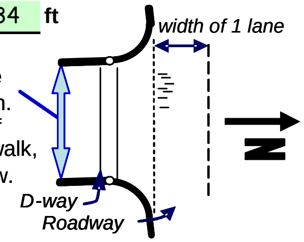
Set the horizontal position of the high or low point 0.0 here

☐ Crest ↓ Sag ➢

this is the side toward the ROADWAY >

D-way width: 34 ft

Measure the typical width of the surface available to drive on. Draw the location of gouge marks, sidewalk, islands, and N arrow.

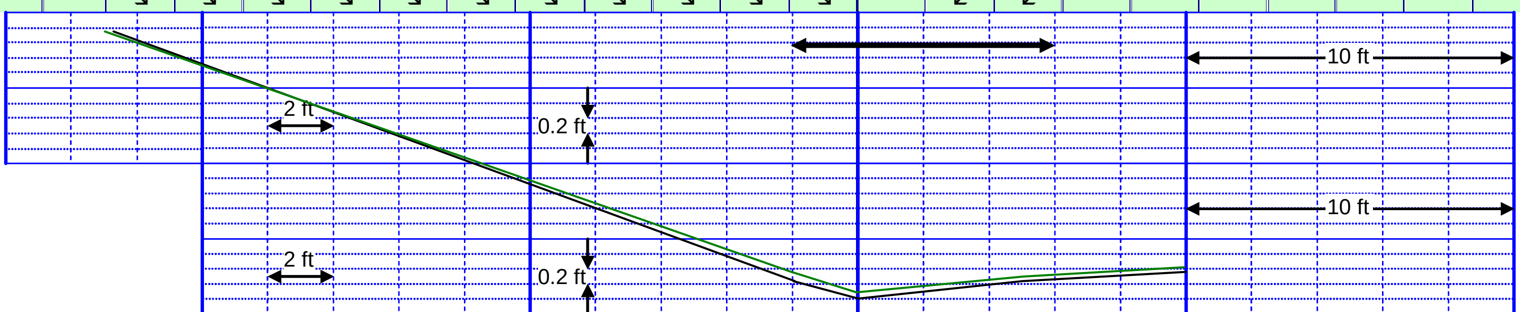


Left of the high/low point (0.0):

Label which side of the d-way: e.g., "south edge" ↓			18 - 20 ft	16 - 18 ft	14 - 16 ft	12 - 14 ft	10 - 12 ft	8 - 10 ft	6 - 8 ft	4 - 6 ft	2 - 4 ft	0 - 2 ft
											scrape 2-0	
Center		23							6		2	0
		4.25									7.42	7.71
							-0.151					-0.145
		↘	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘
WEST (entry)		22.67									2	0
		4.23									7.57	7.79
							-0.162					-0.110
AVERAGE GRADES =							-15.6%					-12.8%

Right of the high/low point (0.0):

Label which side of the d-way: e.g., "south edge" ↓	0 - 2 ft	2 - 4 ft	4 - 6 ft	6 - 8 ft	8 - 10 ft	10 - 12 ft	12 - 14 ft	14 - 16 ft	16 - 18 ft	18 - 20 ft	< the 2 ft. increments
	scrape 0-6										
Center			5		10						
			7.51		7.39						
		0.040		0.024							
		↙	↙								<downhill arrow
WEST (entry)			5		10						
			7.57		7.44						
		0.044		0.026							< %
AVERAGE GRADES =		4.2%									



5
6
7
8

calculated elev = 6.7949 avg = 7.75

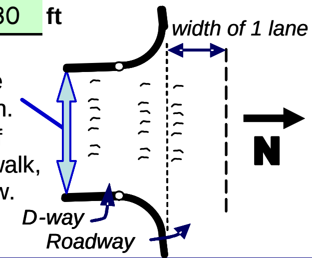
sag 17.0%

< this is the side toward PRIVATE PROPERTY

This form is set up for you to face **toward** oncoming vehicles on the through street.

this is the side toward the ROADWAY >

D-way width: 30 **ft**



Measure the typical width of the surface available to drive on. Draw the location of gouge marks, sidewalk, islands, and N arrow.

Address + Street name: 2501 W. Wm. Cannon

Driveway is in this city, state: Austin, TX

Land use type: professional offices - Stonegate One middle drive

Name : Gattis

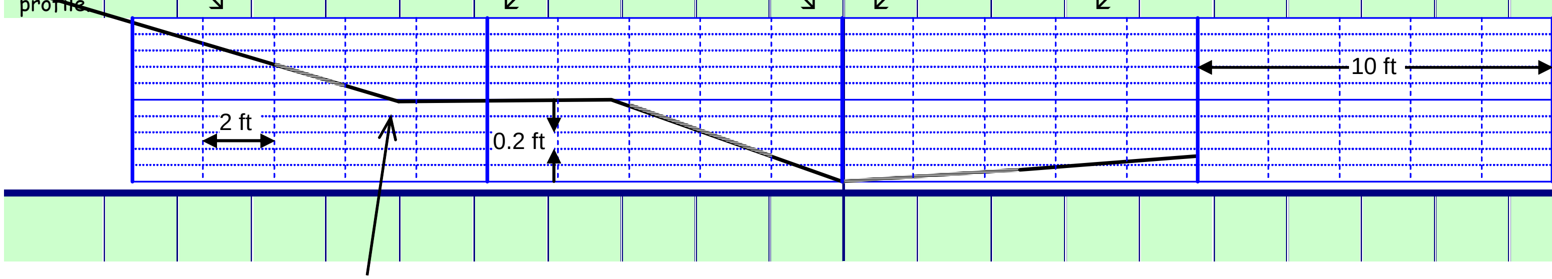
Date measured : Sep. 17, 2007

Land use abbreviations:
apt = apartment com = commercial
SF res = single-family residential

Set the horizontal position of the high or low point 0.0 here ↓

☐ Crest   Sag ☒

Label which side of the d-way: e.g., "south edge" ↓	18 - 20 ft	16 - 18 ft	14 - 16 ft	12 - 14 ft	10 - 12 ft	8 - 10 ft	6 - 8 ft	4 - 6 ft	2 - 4 ft	0 - 2 ft	0 - 2 ft	2 - 4 ft	4 - 6 ft	6 - 8 ft	8 - 10 ft	10 - 12 ft	12 - 14 ft	14 - 16 ft	16 - 18 ft	18 - 20 ft	< the 2 ft. increments
			scrape				< - scrape 7 - 2 ->				< - scrape 0 - 6 ->										
		25-12.5				12.5-6.5				6.5-0	0-5			5-10							
		-13.8				0.30				-15.5	3.1			3.2							< %
Only 1		1.725				-0.018				1.008	0.155			0.160		0.000	0.000	0.000	0.000	0.000	
profile		↘				↙				↘	↙			↙							<downhill arrow



13.5% sag

< this is the side toward PRIVATE PROPERTY

Address + Street name: Cliff @ N. Aqua Crossing
Driveway is in this city, state: Fayetteville, AR
Land use type: apt

Land use abbreviations:
apt = apartment   com = commercial
SF res = single-family residential

This form is set up for you to face **toward** oncoming vehicles on the through street.

Name : Braddy, Reynolds, Nolan
Date measured : Aug 18, 2008

Set the curb face at 0.0

this is the side toward the ROADWAY >

D-way width: 27 ft

Measure the typical width of the surface available to drive on.
Draw the location of gouge marks, sidewalk, islands, and N arrow.

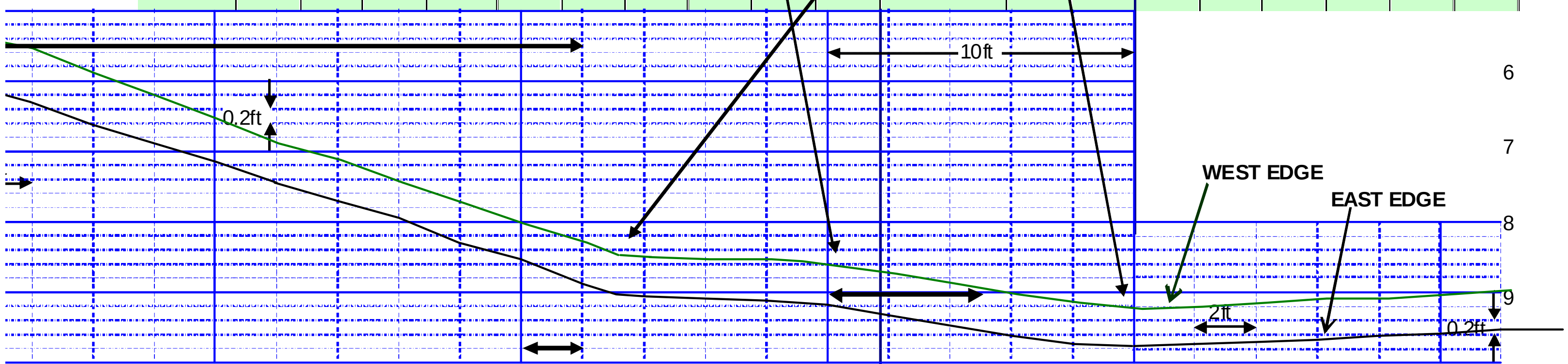
width of 1 lane

D-way
Roadway

N

☐ Crest   Sag ☒   here

Label which side of the d-way: e.g., "south edge"										8 - 10 ft	6 - 8 ft	4 - 6 ft	2 - 4 ft	0 - 2 ft	0 - 2 ft	2 - 4 ft	4 - 6 ft	6 - 8 ft	8 - 10 ft	10 - 12 ft	< the 2 ft. increments	
				< scrape 41-18 ft>			<-- 6' sidewalk -->			< slight scrape 10 - 5 ft>				gutter								
edge	24	22	20	18	17	16	14	12	11	10	8	6	4	2	0	2	4	6	8	10	12	14
WEST	7.46	7.76	8.05	8.34	8.48	8.50	8.52	8.55	8.58	8.62	8.76	8.91	9.04	9.18	9.22	9.20	9.15	9.10	9.07	9.02	8.99	8.93
	-0.150	-0.145	-0.145	-0.140	-0.020	-0.010	-0.015	-0.030	-0.040	-0.070	-0.075	-0.065	-0.070	-0.020	0.010	0.025	0.025	0.015	0.025	0.015	0.030	<downhill arrow



	24	22	20	18	17	16	14	12	11	10	8	6	4	2	0	2	4	6	8	10	12	14
EAST	7.98	8.29	8.56	8.88	9.02	9.05	9.09	9.12	9.15	9.19	9.33	9.47	9.61	9.75	9.77	9.72	9.68	9.64	9.60	9.57	9.54	9.49
	-0.155	-0.134	-0.162	-0.140	-0.030	-0.020	-0.015	-0.030	-0.040	-0.070	-0.070	-0.070	-0.070	-0.010	0.025	0.020	0.020	0.020	0.015	0.015	0.025	< %
					scrape 20-18		<-- 6' sidewalk -->			< slight scrape 10 - 5 ft>				gutter								

22	17	11	4	0	6
7.76	8.48	8.58	9.04	9.22	9.10

-14.4%   -1.7%   -6.6%   2.0%

sag 12.7%   4.9%   **sag 8.6%**

< this is the side toward PRIVATE PROPERTY

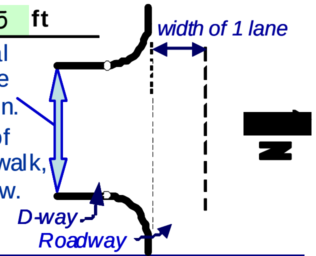
south side of
Address + Street name: Cliff Blvd & Lapis Ln
Driveway is in this city, state: Fayetteville, AR
Land use type: apt

Land use abbreviations:
apt = apartment   com = commercial
SF res = single-family residential

This form is set up for you to face **toward** oncoming vehicles on the through street.
Name : Reese, Reynolds, Nolan
Date measured : Aug 18, 2007

Set the curb face at 0.0

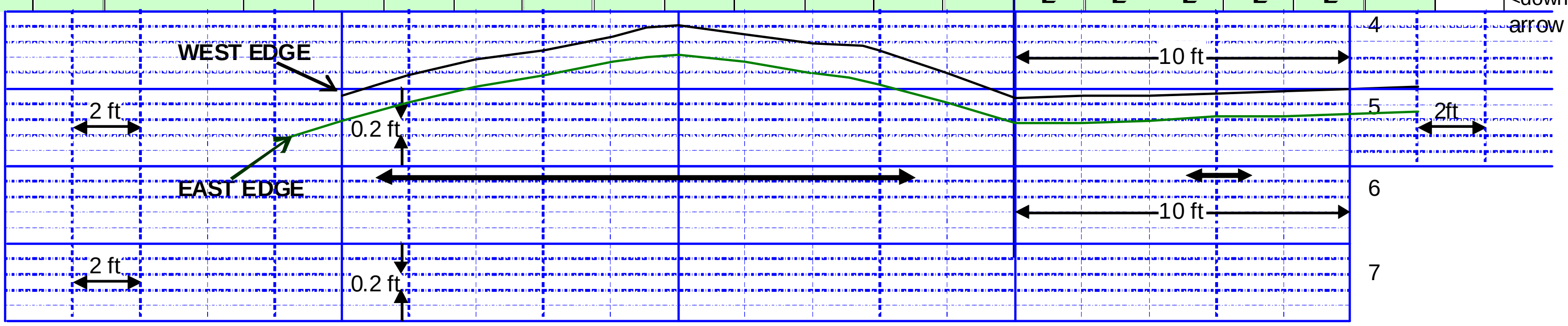
this is the side toward the ROADWAY >
D-way width: 25 **ft**
Measure the typical width of the surface available to drive on.
Draw the location of gouge marks, sidewalk, islands, and N arrow.



☒ Crest   Sag ☒   here ↓

Label which side of the d-way: e.g., "south edge" ↓

								8 - 10 ft	6 - 8 ft			2 - 4 ft	0 - 2 ft	0 - 2 ft	2 - 4 ft	4 - 6 ft	6 - 8 ft	8 - 10 ft	10 - 12 ft	< the 2 ft. increments
					<---------------- scrape 19 - 3						---------------->		gutter		scrape 5-7					
edge	22	20	18	16	14	12	10.9	10	8	6	4.6	4	2	0	2	4	6	8	10	12
WEST	5.35	5.08	4.82	4.62	4.49	4.34	4.21	4.20	4.31	4.41	4.44	4.51	4.81	5.12	5.11	5.08	5.06	5.03	5.01	4.99
	0.135	0.130	0.100	0.065	0.075	0.118	0.011	-0.055	-0.050	-0.021	-0.117	-0.150	-0.155	0.005	0.015	0.010	0.015	0.010	0.010	
														↙	↙	↙	↙	↙		<downhill arrow



	22	20	18	16	14	12	10.9	10	8	6	4.9	4	2	0	2	4	6	8	10	12
EAST	5.68	5.41	5.18	4.97	4.83	4.67	4.60	4.56	4.66	4.78	4.84	4.93	5.19	5.45	5.44	5.41	5.39	5.36	5.34	5.32
	0.135	0.115	0.105	0.070	0.080	0.064	0.044	-0.050	-0.060	-0.055	-0.100	-0.130	-0.130	0.005	0.015	0.010	0.015	0.010	0.010	< %
	↙	↙	↙								↘	↘	↘	↙	↙	↙	↙	↙		

16	11	4.9	0	6
4.97	4.60	4.84	5.45	5.39

7.3%   -4.0%   -12.4%   1.0%

11.3% crest   **13.4% sag**

< this is the side toward PRIVATE PROPERTY

This form is set up for you to face **toward** oncoming vehicles on the through street.

this is the side toward the ROADWAY >

D-way width: 23.5

Address + Street name: Cliff @ E. Peridot

Driveway is in this city, state: Fayetteville, AR

Land use type: apt

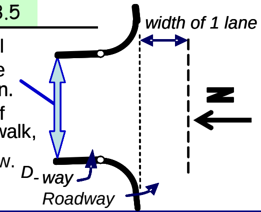
Land use abbreviations:
apt = apartment com = commercial
SF res = single-family residential

Name : Reese, Reynolds, Nolan

Date measured : Aug 14, 2008

Set the curb face at 0.0

Measure the typical width of the surface available to drive on.
Draw the location of gouge marks, sidewalk, islands, and N arrow.

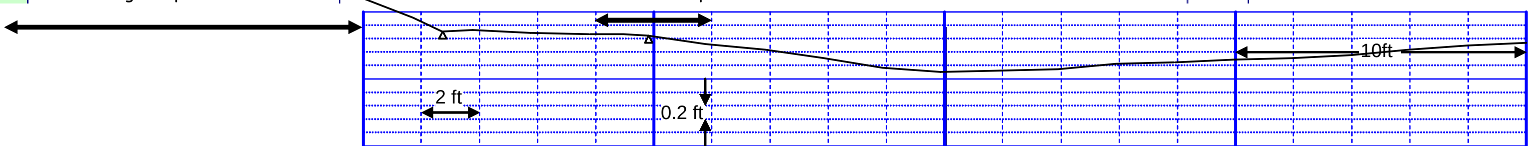


Crest here ↓ Sag

Label which side of the d-way: e.g., "south edge" ↓

		22 - 24 ft		18 - 20 ft			14 - 16 ft	12 - 14 ft			8 - 10 ft	6 - 8 ft	4 - 6 ft	2 - 4 ft	0 - 2 ft	0 - 2 ft	2 - 4 ft	4 - 6 ft	6 - 8 ft	8 - 10 ft	10 - 12 ft	12 - 14 ft	14 - 16 ft	16 - 18 ft	18 - 20 ft	< the 2 ft. increments
W edge	24	**22**	20	18	**17**	**16**	14	12	**10.8**	10	8	**6**	4	2	**0**	2	4	6	8	10	12	14	16	18	20	
	7.10	7.45	7.78	8.11	8.29	8.24	8.28	8.30	8.33	8.36	8.47	8.58	8.70	8.82	8.90	8.87	8.83	8.79	8.76	8.72	8.69	8.64	8.57	8.50	8.44	
		-0.175	-0.165	-0.165	-0.180	0.050	-0.020	-0.010	-0.025	-0.037	-0.055	-0.055	-0.060	-0.060	-0.040	0.015	0.020	0.020	0.015	0.020	0.015	0.025	0.035	0.035	0.030	< %

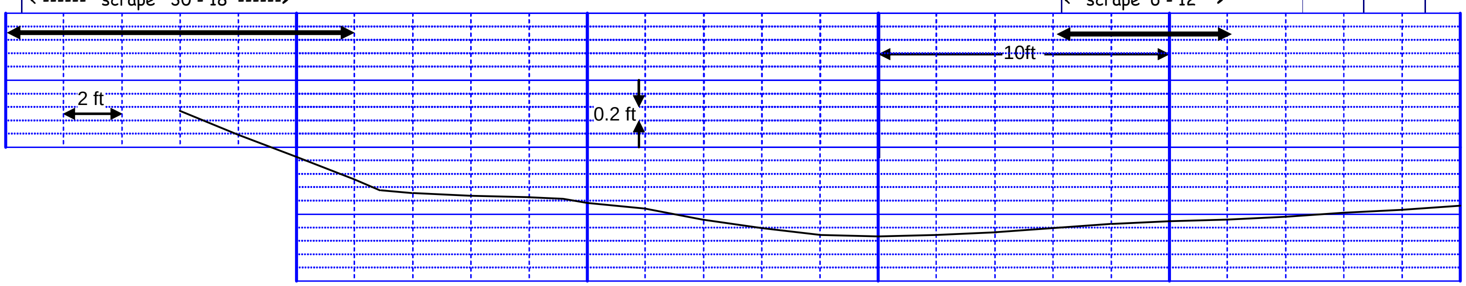
‹ ------ sag scrape 32 - 20 ------› ‹ few crest scrapes 12-8 ›



E edge	24	22	20	18	17	16	14	12	10.8	10	8	6	4	2	0	2	4	6	8	10	12	14	16	18	20	
	7.45	7.81	8.15	8.48	8.64	8.68	8.72	8.76	8.79	8.82	8.95	9.07	9.20	9.33	9.35	9.30	9.24	9.21	9.16	9.12	9.09	9.03	8.98	8.92	8.86	
		-0.180	-0.170	-0.165	-0.160	-0.040	-0.020	-0.020	-0.025	-0.038	-0.065	-0.060	-0.065	-0.065	-0.010	0.025	0.030	0.015	0.025	0.020	0.015	0.030	0.025	0.030	0.030	< %

‹ ------ scrape 30 - 18 ------› ‹ scrape 6 - 12 ›

arrow



22	17	16	10.8	6	0	12	
7.45	8.29	8.24	8.33	8.58	8.90	8.69	

-16.8% -1.7% -5.2% -5.3% 1.8%

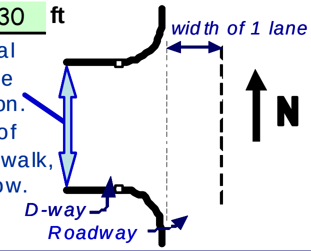
sag 15.1% **crest 3.5%** sag 7.1% < not a cause

< this is the side toward PRIVATE PROPERTY

This form is set up for you to face **toward** oncoming vehicles on the through street.

this is the side toward the ROADWAY >

D-way width: 30 **ft**



Address + Street name: 1831 N. Crossover

Driveway is in this city, state: Fayetteville, AR

Land use type: com - Automatic Car Wash

Land use abbreviations:

Apt = apartment Com = commercial

SF Res = single-family residential

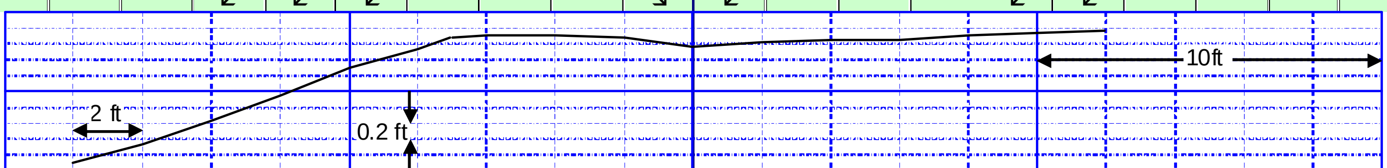
Name : Reese, Nolan

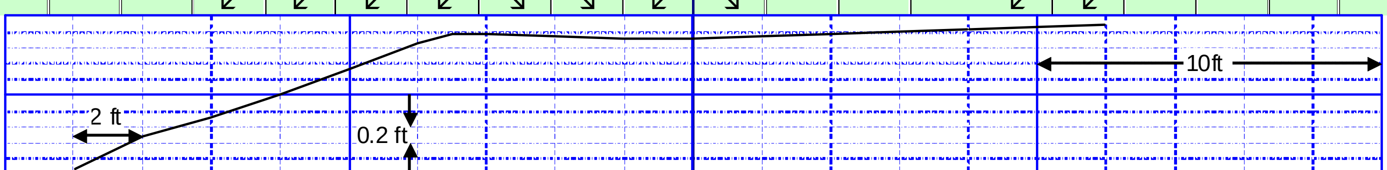
Date measured : Aug 18, 2008

Set the curb face at 0.0

Crest here ↓ Sag

Label which side of the d-way: e.g., "south edge" ↓	18 - 20 ft	16 - 18 ft	14 - 16 ft	12 - 14 ft	10 - 12 ft	8 - 10 ft	6 - 8 ft	4 - 6 ft	2 - 4 ft	0 - 2 ft	0 - 2 ft	2 - 4 ft	4 - 6 ft	6 - 8 ft	8 - 10 ft	10 - 12 ft	12 - 14 ft	14 - 16 ft	16 - 18 ft	18 - 20 ft	< the 2 ft. increments
						<-- scrape 10 - 4 -->															
N edge (entry)	18	16	14	12	10	8	6.8	6	4	2	0	2	4	6	8	10	12				
	4.92	4.66	4.39	4.04	3.71	3.45	3.32	3.30	3.31	3.32	3.43	3.37	3.36	3.34	3.29	3.27	3.23				
	0.130	0.135	0.175	0.165	0.130	0.108	0.025	-0.005	-0.005	-0.055	0.030	0.005	0.010	0.025	0.010	0.020					< %
				↙	↙	↙				↘	↙				↙	↙					<downhill arrow
S edge (exit)	18	16	14	12	10	8	6.8	6	4	2	0	2	4	6	8	10	12				
	3.95	3.64	3.32	2.99	2.67	2.36	2.21	2.21	2.23	2.26	2.32	2.24	2.23	2.20	2.17	2.15	2.11				
	0.155	0.160	0.165	0.160	0.155	0.125	0.000	-0.010	-0.015	-0.030	0.040	0.005	0.015	0.015	0.010	0.020					< %
				↙	↙	↙	↙	↘	↘	↙	↘				↙	↙					<downhill arrow





14 6.8 2

3.32 2.21 2.26

15.4% -1.0%

crest 16.5%

< this is the side toward PRIVATE PROPERTY

Address + Street name: W. Dickson St. (SE Bldg.)
Driveway is in this city, state: Fayetteville, AR
Land use type: university classroom/office

Land use abbreviations:
Apt = apartment Com = commercial
SF Res = single-family residential

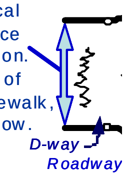
This form is set up for you to face toward oncoming vehicles on the through street.
Name : Reese, Reynolds
Date measured : Sep. 8, 2008

Set the horizontal position of the high or low point 0.0 here ↓

☐ Crest Sag ☐

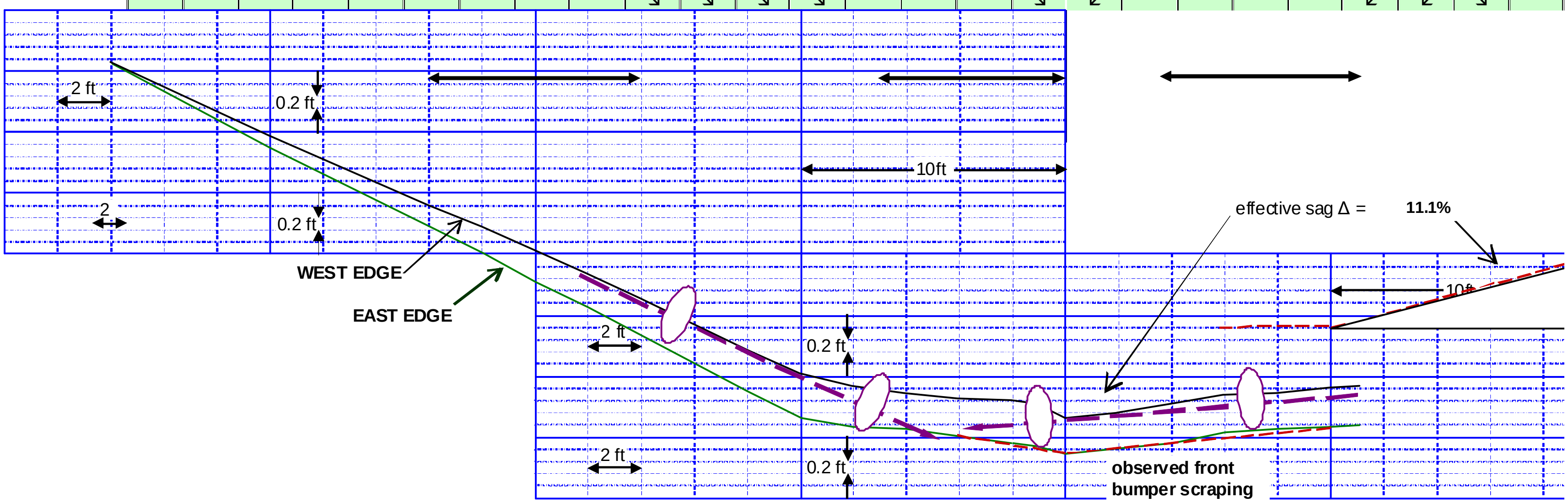
this is the side toward the
D-way width: 25 **ft**

Measure the typical width of the surface available to drive on.
Draw the location of gouge marks, sidewalk, islands, and N arrow.



Label which side of the d-way: e.g., "south ↓

																	0 - 2 ft	2 - 4 ft	4 - 6 ft	6 - 8 ft	8 - 10 ft	10 - 12 ft	12 - 14 ft	14 - 16 ft	16 - 18 ft
							< scrape 24-16 >							< scrape 7 - 0 >					< scrape 3.5 - 11 >						
W edge (exit)	36	30	24	22	20	18	16	14	12	10	8	6	4	2	1	0	2	4	6	8	10	11			
	2.84	4.05	5.20	5.56	5.95	6.33	6.73	7.14	7.58	7.97	8.18	8.29	8.36	8.40	8.44	8.67	8.61	8.43	8.30	8.25	8.18	8.15			
		-0.202	-0.192	-0.180	-0.195	-0.190	-0.200	-0.205	-0.220	-0.195	-0.105	-0.055	-0.035	-0.020	-0.040	-0.230	0.030	0.090	0.065	0.025	0.035	0.030			
									↘	↘	↘	↘				↘	↙					↙	↙	↘	



E edge (entry)	36	30	24	22	20	18	16	14	12	10	8	6	4	2	1	0	2	4	6	8	10	11			
	2.87	4.25	5.55	5.99	6.44	6.84	7.31	7.78	8.25	8.68	8.83	8.87	8.97	9.10	9.15	9.26	9.19	9.08	8.94	8.89	8.83	8.80			
		-0.230	-0.217	-0.220	-0.225	-0.200	-0.235	-0.235	-0.235	-0.215	-0.075	-0.020	-0.050	-0.065	-0.050	-0.110	0.035	0.055	0.070	0.025	0.030	0.030			

< this is the side toward PRIVATE PROPERTY

Address + Street name: 41 S. Gregg
Driveway is in this city, state: Fayetteville, AR
Land use type: apt - Myers' Apts

Land use abbreviations:
apt = apartment com = commercial
SF res = single-family residential

This form is set up for you to face **toward** oncoming vehicles on the through street.

Name : Braddy, Reynolds
Date measured : May 20, 2008

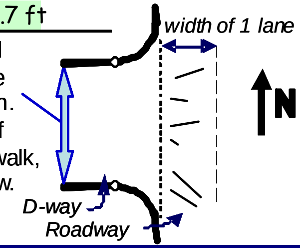
Set the road edge at 0.0 here ↓

☐ Crest   Sag ☒

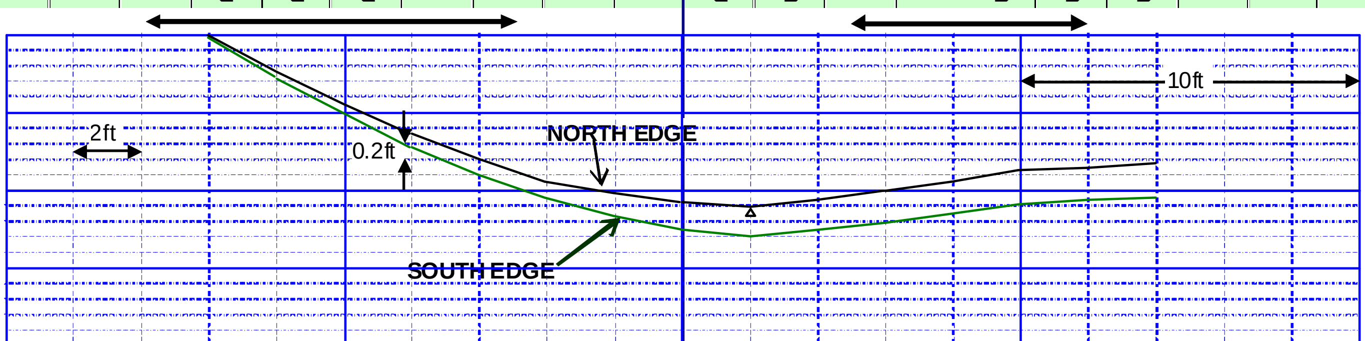
this is the side toward the ROADWAY >

D-way width: 13.7 ft

Measure the typical width of the surface available to drive on. Draw the location of gouge marks, sidewalk, islands, and N arrow.



Label which side of the d-way: e.g., "south edge" ↓	18 - 20 ft	16 - 18 ft	14 - 16 ft	12 - 14 ft	10 - 12 ft	8 - 10 ft	6 - 8 ft	4 - 6 ft	2 - 4 ft	0 - 2 ft	0 - 2 ft	2 - 4 ft	4 - 6 ft	6 - 8 ft	8 - 10 ft	10 - 12 ft	12 - 14 ft	14 - 16 ft	16 - 18 ft	18 - 20 ft	< the 2 ft. increments
			<	scrape	16 -	5	>							< scrape	5 -12	>					
N edge			14	12	10	8	6	**4**	2	0	**2**	4	6	**8**	10	12	14				
			4.02	4.50	4.91	5.28	5.62	5.90	6.05	6.15	6.20	6.13	6.01	5.89	5.78	5.72	5.69				
				-0.240	-0.205	-0.185	-0.170	-0.140	-0.075	-0.050	-0.025	0.035	0.060	0.060	0.055	0.030	0.015				< %
				↘	↘	↘					↘	↙			↙	↙	↙				<downhill arrow
S edge			14	12	10	8	6	4	2	0	2	4	6	8	10	12	14				
			4.08	4.58	5.05	5.46	5.81	6.11	6.35	6.51	6.59	6.54	6.43	6.31	6.20	6.14	6.09				
				-0.250	-0.235	-0.205	-0.175	-0.150	-0.120	-0.080	-0.040	0.025	0.055	0.060	0.055	0.030	0.025				< %
				↘	↘	↘					↘	↙			↙	↙	↙				<downhill arrow



4	2	8
5.9	6.2	5.89
-5.0%	5.2%	

10.2% sag

< this is the side toward PRIVATE PROPERTY

Address + Street name: 2730 Hyland Park Rd.
Driveway is in this city, state: Fayetteville, AR
Land use type: SF res

Land use abbreviations:
apt = apartment com = commercial
SF res = single-family residential

This form is set up for you to face **toward** oncoming vehicles on the through street.

Name : Braddy, Reynolds
Date measured : May 21, 2008
Calculations : Reese

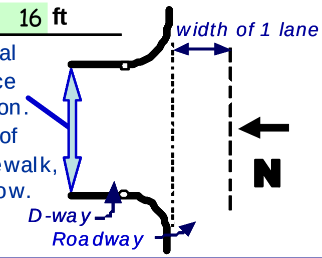
Set the curb face at 0.0 here ↓

☐ Crest Sag ☒

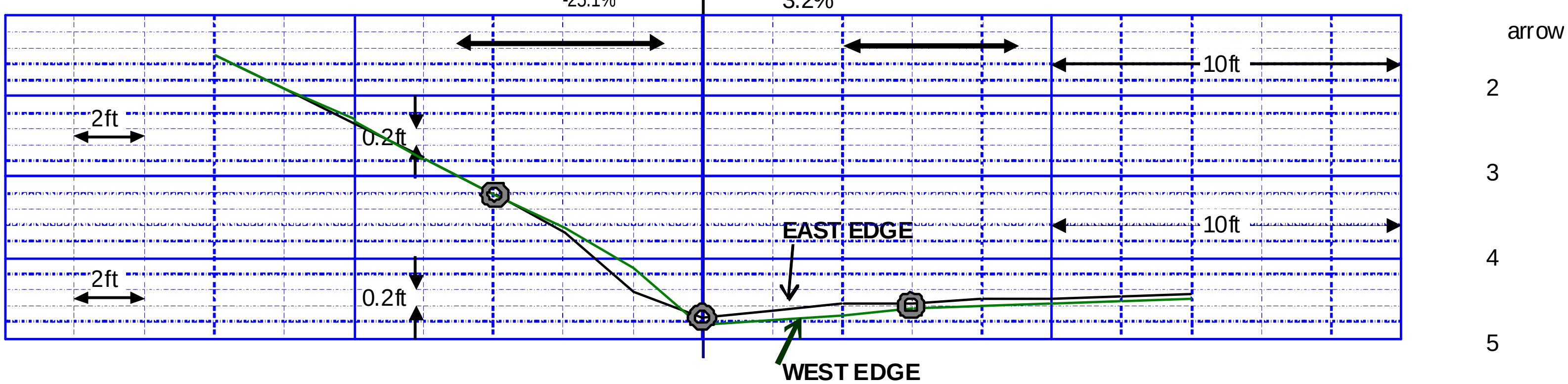
this is the side toward the ROADWAY >

D-way width: 16 **ft**

Measure the typical width of the surface available to drive on. Draw the location of gouge marks, sidewalk, islands, and N arrow.



Label which side of the d-way: e.g., "south edge" ↓	18 - 20 ft	16 - 18 ft	14 - 16 ft	12 - 14 ft	10 - 12 ft	8 - 10 ft	6 - 8 ft	4 - 6 ft	2 - 4 ft	0 - 2 ft	0 - 2 ft	2 - 4 ft	4 - 6 ft	6 - 8 ft	8 - 10 ft	10 - 12 ft	12 - 14 ft	14 - 16 ft	16 - 18 ft	18 - 20 ft	< the 2 ft. increments
							< --- scrape 7 - 1 --->						scrape 4 - 9								
E edge			14	12	10	8	6	4	2	0	2	4	6	8	10	12	14				
			1.52	1.94	2.36	2.77	3.22	3.68	4.41	4.73	4.64	4.59	4.54	4.50	4.49	4.48	4.46				
				-0.210	-0.210	-0.205	-0.225	-0.230	-0.365	-0.160	0.045	0.025	0.025	0.020	0.005	0.005	0.010				< %
				↘	↘	↘				↘	↙				↙	↙	↙				<downhill arrow
									-25.1%			3.2%									



	18 - 20 ft	16 - 18 ft	14 - 16 ft	12 - 14 ft	10 - 12 ft	8 - 10 ft	6 - 8 ft	4 - 6 ft	2 - 4 ft	0 - 2 ft	0 - 2 ft	2 - 4 ft	4 - 6 ft	6 - 8 ft	8 - 10 ft	10 - 12 ft	12 - 14 ft	14 - 16 ft	16 - 18 ft	18 - 20 ft	
W edge			14	12	10	8	6	4	2	0	2	4	6	8	10	12	14				
			1.48	1.90	2.34	2.79	3.21	3.65	4.15	4.84	4.78	4.71	4.65	4.61	4.56	4.54	4.51				
				-0.210	-0.220	-0.225	-0.210	-0.220	-0.250	-0.345	0.030	0.035	0.030	0.020	0.025	0.010	0.015				< %
				↘	↘	↘				↘	↙				↙	↙	↙				<downhill arrow
									-27.1%			3.2%									

< this is the side toward PRIVATE PROPERTY

This form is set up for you to face **toward** oncoming vehicles on the through street.

this is the side toward the ROADWAY >

D-way width: 23 **ft**

Address + Street name: Lafayette west of College (middle driveway) Name Braddy, Reynolds, Reese

Driveway is in this city, state: Fayetteville, AR Date measured : May 22, 2008

Land use type: com - Valero c-store/gas

Land use abbreviations:
apt = apartment com = commercial
SF res = single-family residential

Measure the typical width of the surface available to drive on. Draw the location of gouge marks, sidewalk, islands, and N arrow.

width of 1 lane

D-way

Roadway

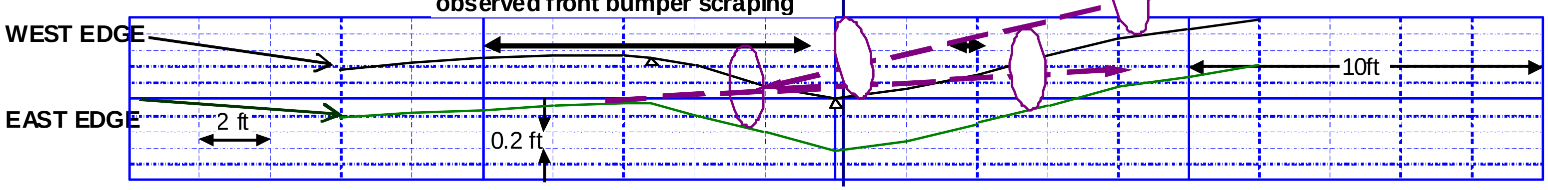
N

Set the curb face at 0.0 here ↓

☒ Crest Sag ☒

Label which side of the d-way: e.g., "south edge" ↓	18 - 20 ft	16 - 18 ft	14 - 16 ft	12 - 14 ft	10 - 12 ft	8 - 10 ft	6 - 8 ft	4 - 6 ft	2 - 4 ft	0 - 2 ft	0 - 2 ft	2 - 4 ft	4 - 6 ft	6 - 8 ft	8 - 10 ft	10 - 12 ft	12 - 14 ft	14 - 16 ft	16 - 18 ft	18 - 20 ft	< the 2 ft. increments
						< scrape	10 - 1	>				scrape 3-4									
W edge			14	12	**10**	8	6	**5.2**	4	2	**0**	2	4	**6**	8	10	12				
			5.61	5.56	5.51	5.47	5.47	5.48	5.58	5.81	6.00	5.87	5.69	5.5	5.26	5.15	5.01				
				0.025	0.025	0.020	0.000	-0.013	-0.083	-0.115	0.095	0.065	0.090	0.100	0.115	0.055	0.070				< %
				↙	↙	↙			↘	↘	↙	↙									<downhill arrow

observed front bumper scraping



6

7

observed rear of delivery truck close to scraping

E edge			14	12	10	8	6	5.2	4	2	0	2	4	6	8	10	12				
			6.20	6.16	6.13	6.09	6.06	6.06	6.19	6.40	6.62	6.49	6.29	6.07	5.83	5.73	5.59				
				0.020	0.015	0.020	0.015	0.000	-0.108	-0.105	0.110	0.065	0.100	0.110	0.120	0.050	0.070				< %
				↙	↙	↙				↘	↘	↙	↙								<downhill 5 arrow

10	5.2	0	6
5.51	5.48	6.00	5.49

0.6% -10.0% 8.5%

crest 10.6% 18.5% sag

< this is the side toward PRIVATE PROPERTY

Address + Street name: 1813 Mission
Driveway is in this city, state: Fayetteville, AR
Land use type: com - Tim's Pizza sw side

Land use abbreviations:
apt = apartment   com = commercial
SF res = single-family residential

This form is set up for you to face **toward** oncoming vehicles on the through street.

Name : Braddy, Reynolds, Reese
Date measured : May 22, 2008

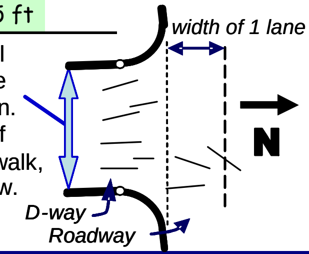
Set the road edge at 0.0 here ↓

☐ Crest   Sag ☒

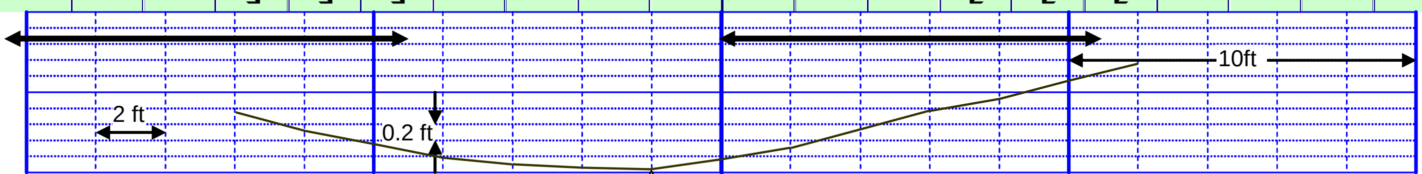
this is the side toward the ROADWAY >

D-way width: 25 ft

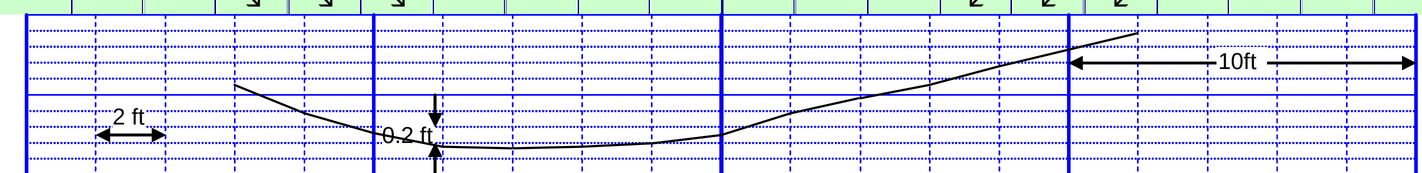
Measure the typical width of the surface available to drive on. Draw the location of gouge marks, sidewalk, islands, and N arrow.



Label which side of the d way: e.g., "south edge" ↓	18 - 20 ft	16 - 18 ft	14 - 16 ft	12 - 14 ft	10 - 12 ft	8 - 10 ft	6 - 8 ft	4 - 6 ft	2 - 4 ft	0 - 2 ft	0 - 2 ft	2 - 4 ft	4 - 6 ft	6 - 8 ft	8 - 10 ft	10 - 12 ft	12 - 14 ft	14 - 16 ft	16 - 18 ft	18 - 20 ft	< the 2 ft. increments
	<	scrape	22 - 9		>						<	scrape	0 - 11		>						
W edge			14	12	10	**8**	6	4	**2**	0	2	**4**	6	8	10	12					
			5.26	5.48	5.64	5.81	5.89	5.94	5.96	5.82	5.67	5.44	5.23	5.09	4.85	4.65					
				-0.110	-0.080	-0.085	-0.040	-0.025	-0.010	0.070	0.075	0.115	0.105	0.070	0.120	0.100					< %
				↘	↘	↘								↙	↙	↙					<downhill arrow



	18 - 20 ft	16 - 18 ft	14 - 16 ft	12 - 14 ft	10 - 12 ft	8 - 10 ft	6 - 8 ft	4 - 6 ft	2 - 4 ft	0 - 2 ft	0 - 2 ft	2 - 4 ft	4 - 6 ft	6 - 8 ft	8 - 10 ft	10 - 12 ft	12 - 14 ft	14 - 16 ft	16 - 18 ft	18 - 20 ft	
E edge			14	12	10	8	6	4	2	0	2	4	6	8	10	12					
			5.89	6.23	6.48	6.64	6.66	6.64	6.60	6.46	6.22	6.04	5.86	5.64	5.44	5.22					
				-0.170	-0.125	-0.080	-0.010	0.010	0.020	0.070	0.120	0.090	0.090	0.110	0.100	0.110					< %
				↘	↘	↘								↙	↙	↙					<downhill arrow



8	2	4
5.81	5.96	5.44

-2.5%   8.7%

11.2%   **sag**

< this is the side toward PRIVATE PROPERTY

north side of
Address + Street name: North St. west of Leverett
Driveway is in this city, state: Fayetteville, AR
Land use type: apt North St. Condos

Land use abbreviations:
apt = apartment com = commercial
SF res = single-family residential

This form is set up for you to face **toward** oncoming vehicles on the through street.
Name : Gattis,Reynolds
Date measured : Aug 19, 2008

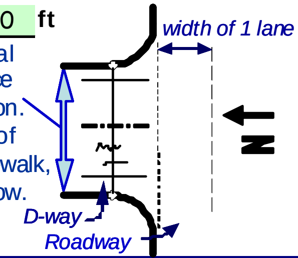
Set the curb face at 0.0

☒ Crest Sag ☐

this is the side toward the ROADWAY >

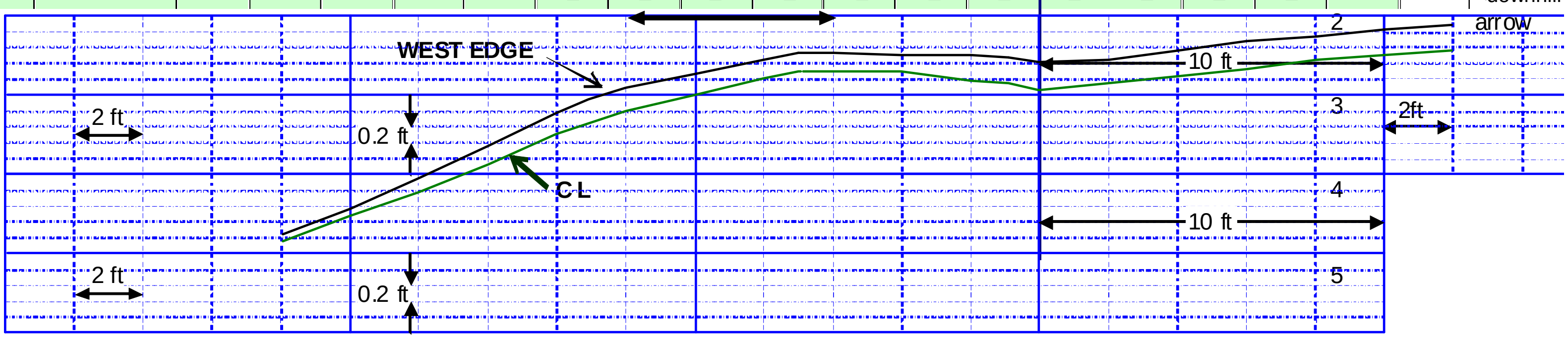
D-way width: 20 **ft**

Measure the typical width of the surface available to drive on. Draw the location of gouge marks, sidewalk, islands, and N arrow.



here ↓

Label which side of the d-way: e.g., "south edge" ↓	22	20	18	16	14	13	12	10	8	7	6	4	2	0.8	0	2	4	6	8	10	12
							10-12 ft	8 - 10 ft				2 - 4 ft			0 - 2 ft	2 - 4 ft	4 - 6 ft	6 - 8 ft	8 - 10 ft	< the 2 ft. increments	
								<- slight scrape 12-6 -> 6 ft sidewalk						gutter							
edge	22	20	18	16	14	13	**12**	10	8	**7**	6	4	2	**0.8**	0	2	4	6	8	10	12
WEST gutter	4.75	4.41	4.04	3.65	3.22	3.02	2.91	2.73	2.55	2.44	2.44	2.48	2.51	2.53	2.59	2.55	2.44	2.33	2.29	2.19	2.13
seam; 8.9	0.170	0.185	0.195	0.215	0.200	0.110	0.090	0.090	0.110	0.000	-0.020	-0.015	-0.017	-0.075	0.020	0.055	0.055	0.020	0.050	0.030	
ft from CL								↙	↙	↙	↘	↘	↘	↘	↙	↙	↙	↙			<downhill arrow



C L	22	20	18	16	14	12	10	8	7	6.9	6	4	2	0.8	0	2	4	6	8	10	12
	4.86	4.53	4.22	3.89	3.54	3.21	3.00	2.80	2.72	2.70	2.70	2.76	2.81	2.85	2.91	2.86	2.75	2.65	2.59	2.50	2.45
	0.165	0.155	0.165	0.175	0.165	0.105	0.100	0.080	0.200	0.000	-0.030	-0.025	-0.033	-0.075	0.025	0.055	0.050	0.030	0.045	0.025	< %

12	7	0.8
2.91	2.44	2.53
9.4%	-1.5%	

crest 10.9% ✓

< this is the side toward PRIVATE PROPERTY

Address + Street name: 583 Rock Cliff
Driveway is in this city, state: Fayetteville, AR
Land use type: SF res

Land use abbreviations:
apt = apartment   com = commercial
SF res = single-family residential

This form is set up for you to face **toward** oncoming vehicles on the through street.

Name : Braddy, Reynolds
Date measured : May 21, 2008
Calculations : Reese

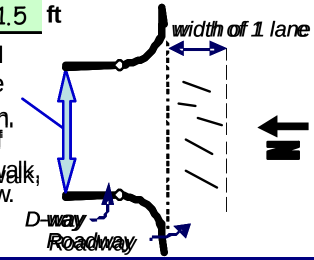
Set the curb face at 0.0 here ↓

☐ Crest   Sag ☒

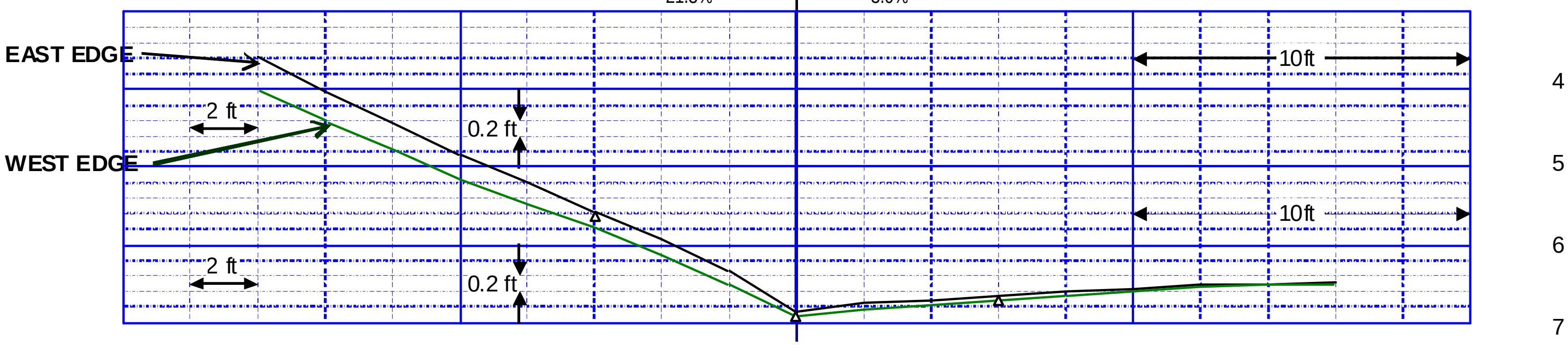
this is the side toward the ROADWAY >

D-way width: 11.5 **ft**

Measure the typical width of the surface available to drive on. Draw the location of gouge marks, sidewalk, islands, and N arrow.



Label which side of the d-way: e.g., "south edge" ↓	18 - 20 ft	16 - 18 ft	14 - 16 ft	12 - 14 ft	10 - 12 ft	8 - 10 ft	6 - 8 ft	4 - 6 ft	2 - 4 ft	0 - 2 ft	0 - 2 ft	2 - 4 ft	4 - 6 ft	6 - 8 ft	8 - 10 ft	10 - 12 ft	12 - 14 ft	14 - 16 ft	16 - 18 ft	18 - 20 ft	< the 2 ft. increments
E edge		16	14	12	10	8	6	4	2	0	2	4	6	8	10	12	14	16			
		3.58	4.01	4.41	4.84	5.20	5.58	5.95	6.35	6.86	6.75	6.71	6.66	6.61	6.57	6.52	6.49	6.48			
			-0.215	-0.200	-0.215	-0.180	-0.190	-0.185	-0.200	-0.255	0.055	0.020	0.025	0.025	0.020	0.025	0.015	0.005			< %
			↘	↘	↘					↘	↙					↙	↙	↙			<downhill arrow
									-21.3%			3.0%									



	18 - 20 ft	16 - 18 ft	14 - 16 ft	12 - 14 ft	10 - 12 ft	8 - 10 ft	6 - 8 ft	4 - 6 ft	2 - 4 ft	0 - 2 ft	0 - 2 ft	2 - 4 ft	4 - 6 ft	6 - 8 ft	8 - 10 ft	10 - 12 ft	12 - 14 ft	14 - 16 ft	16 - 18 ft	18 - 20 ft	
W edge		16	14	12	10	8	6	4	2	0	2	4	6	8	10	12	14	16			
		4.01	4.39	4.78	5.15	5.46	5.78	6.13	6.48	6.91	6.81	6.75	6.71	6.65	6.60	6.55	6.52	6.54			
			-0.190	-0.195	-0.185	-0.155	-0.160	-0.175	-0.175	-0.215	0.050	0.030	0.020	0.030	0.025	0.025	0.015	-0.010			< %
				↘	↘	↘				↘	↙					↙	↙				<downhill arrow
									-18.8%			3.3%									

< this is the side toward PRIVATE PROPERTY

Address + Street name: 599 Rock Cliff
Driveway is in this city, state: Fayetteville, AR
Land use type: SF res

Land use abbreviations:
apt = apartment com = commercial
SF res = single-family residential

This form is set up for you to face **toward** oncoming vehicles on the through street.

Name : Braddy, Reynolds
Date measured : May 20, 2008
Calculations : Reese

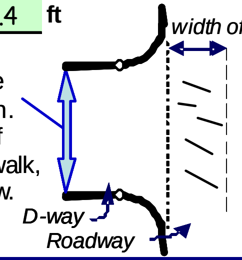
Set the curb face at 0.0 here ↓

☐ Crest Sag ☒

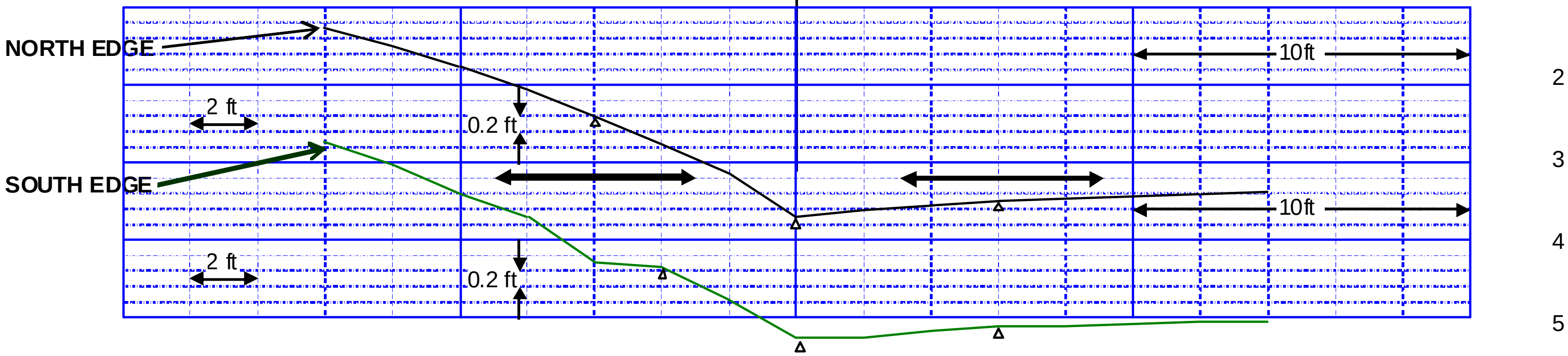
this is the side toward the ROADWAY >

D-way width: 12.4 **ft**

Measure the typical width of the surface available to drive on. Draw the location of gouge marks, sidewalk, islands, and N arrow.



Label which side of the d-way: e.g., "south edge" ↓	18 - 20 ft	16 - 18 ft	14 - 16 ft	12 - 14 ft	10 - 12 ft	8 - 10 ft	6 - 8 ft	4 - 6 ft	2 - 4 ft	0 - 2 ft	0 - 2 ft	2 - 4 ft	4 - 6 ft	6 - 8 ft	8 - 10 ft	10 - 12 ft	12 - 14 ft	14 - 16 ft	16 - 18 ft	18 - 20 ft	< the 2 ft. increments
						< -- scrape 9 - 3 -->						< -- scrape 3 - 9 -->									
N edge			14	12	10	8	6	4	2	0	2	4	6	8	10	12	14				
			1.25	1.48	1.78	2.06	2.42	2.77	3.18	3.72	3.62	3.57	3.52	3.48	3.44	3.41	3.39				
				-0.115	-0.150	-0.140	-0.180	-0.175	-0.205	-0.270	0.050	0.025	0.025	0.020	0.020	0.015	0.010				< %
				↘	↘	↘				↘	↙				↙	↙	↙				<downhill arrow
									-21.6%		3.0%										



S edge			14	12	10	8	6	4	2	0	2	4	6	8	10	12	14				
			2.74	3.05	3.40	3.72	4.30	4.33	4.74	5.23	5.22	5.18	5.14	5.11	5.09	5.05	5.03				
				-0.155	-0.175	-0.160	-0.290	-0.015	-0.205	-0.245	0.005	0.020	0.020	0.015	0.010	0.020	0.010				< %
				↘	↘	↘				↘	↙				↙	↙	↙				<downhill arrow
									-22.5%		1.5%										

< this is the side toward PRIVATE PROPERTY

Address + Street name: St. Charles north of Dickson

Driveway is in this city, state: Fayetteville, AR

Land use type: com - Colliers' Drug

Land use abbreviations:

apt = apartment com = commercial

SF res = single-family residential

This form is set up for you to face **toward** oncoming vehicles on the through street.

Name : Braddy

Date measured : May 19, 2008

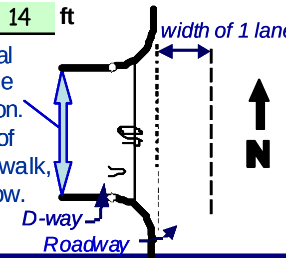
Set the curb face at 0.0 here ↓

☐ Crest Sag ☒

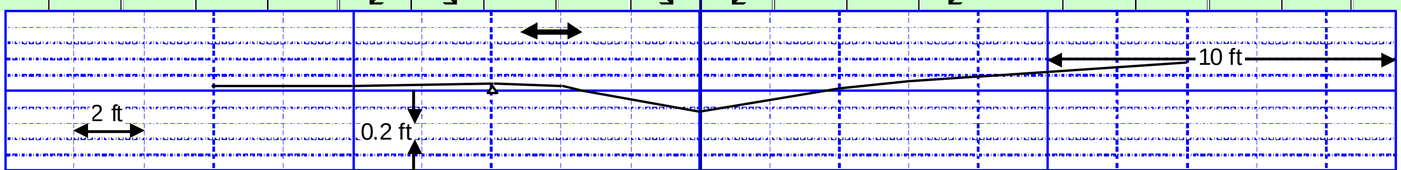
this is the side toward the ROADWAY >

D-way width: 14 **ft**

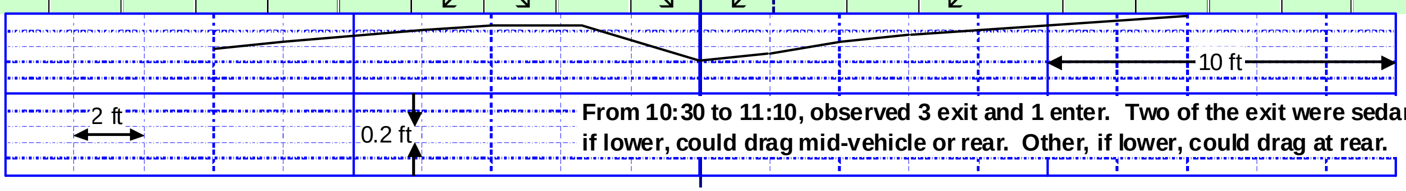
Measure the typical width of the surface available to drive on. Draw the location of gouge marks, sidewalk, islands, and N arrow.



Label which side of the d-way: e.g., "south edge" ↓	18 - 20 ft	16 - 18 ft	14 - 16 ft	12 - 14 ft	10 - 12 ft	8 - 10 ft	6 - 8 ft	4 - 6 ft	2 - 4 ft	0 - 2 ft	0 - 2 ft	2 - 4 ft	4 - 6 ft	6 - 8 ft	8 - 10 ft	10 - 12 ft	12 - 14 ft	14 - 16 ft	16 - 18 ft	18 - 20 ft	< the 2 ft. increments
								scrape 5 - 3.5													
N edge			14	12	10	8	6	4	3.6	2	0	2	4	6	8	10	12	14			
			4.94	4.92	4.92	4.90	4.89	4.91	5.00	5.12	5.24	5.09	4.96	4.87	4.81	4.75	4.71	4.65			
				0.010	0.000	0.010	0.005	-0.010	-0.225	-0.075	0.060	0.075	0.065	0.045	0.030	0.030	0.020	0.030			< %
						↙	↘			↘	↙			↙							<downhill arrow



Label which side of the d-way: e.g., "south edge" ↓	18 - 20 ft	16 - 18 ft	14 - 16 ft	12 - 14 ft	10 - 12 ft	8 - 10 ft	6 - 8 ft	4 - 6 ft	2 - 4 ft	0 - 2 ft	0 - 2 ft	2 - 4 ft	4 - 6 ft	6 - 8 ft	8 - 10 ft	10 - 12 ft	12 - 14 ft	14 - 16 ft	16 - 18 ft	18 - 20 ft	< the 2 ft. increments
S edge			14	12	10	8	6	4	3.6	2	0	2	4	6	8	10	12	14			
			4.44	4.35	4.29	4.20	4.16	4.14	4.15	4.36	4.57	4.49	4.36	4.26	4.19	4.12	4.07	4.03			
				0.045	0.030	0.045	0.020	0.010	-0.025	-0.131	0.105	0.040	0.065	0.050	0.035	0.035	0.025	0.020			< %
							↙	↘		↘	↙			↙							<downhill arrow



From 10:30 to 11:10, observed 3 exit and 1 enter. Two of the exit were sedans. One, if lower, could drag mid-vehicle or rear. Other, if lower, could drag at rear.

10		4		0		6
4.92		4.91		5.24		4.87
	-0.2%		-8.3%		6.2%	
	crest	8.1%		**14.4% sag**		

Driveway is used mostly by exiting vehicles;

< assumed that scrapes are from rear bumper, so is a Sag situation

< this is the side toward PRIVATE PROPERTY

This form is set up for you to face **toward** oncoming vehicles on the through street.

this is the side toward the ROADWAY >

D-way width: 28.5 **ft**

Address + Street name: Sapphire Dr. @ Aqua Crossing

Driveway is in this city, state: Fayetteville, AR

Land use type: apt - Aqua Crossing

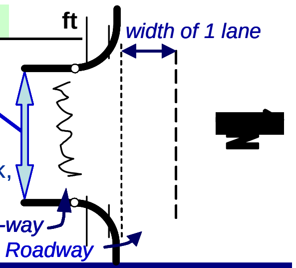
Name : Gattis

Date measured : July 8, 2007

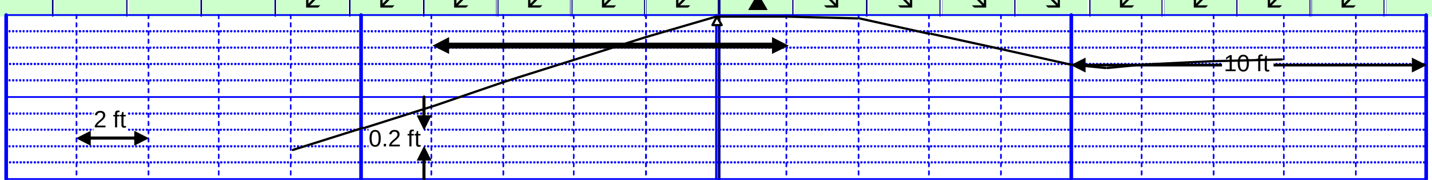
Land use abbreviations:
apt = apartment   com = commercial
SF res = single-family residential

Set the horizontal position of the high or low point 0.0 here ↓

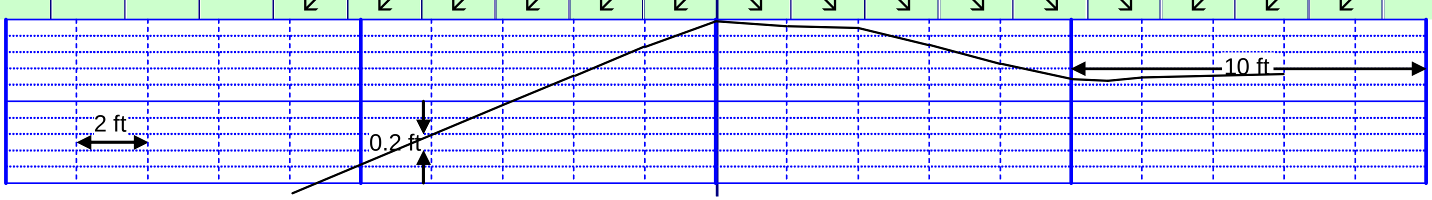
☒ Crest   Sag ☐



Label which side of the d-way: e.g., "south edge" ↓	18 - 20 ft	16 - 18 ft	14 - 16 ft	12 - 14 ft	10 - 12 ft	8 - 10 ft	6 - 8 ft	4 - 6 ft	2 - 4 ft	0 - 2 ft											< the 2 ft. increments
	① ENTER the % grade for the 2 ft or other increment; ② draw arrow to indicate slope; ③ draw the profile w/ scrape marks located.																				
							scrape	scrape	scrape	scrape	scrape				< gutter @ 6 ft						
west edge										0 - 2 ft	Crest; 4 ft wide sidewalk		0 - 2 ft	2 - 4 ft	4 - 6 ft	6 - 8 ft	7 - 8 ft	8 - 10 ft	10 - 12 ft		
					14.1	14.2	15.2	**14.5**	**14.1**	**12.0**	**0.0**	**-0.8**	-9.3	-10.1	-9.2	3.2	1.8	1.8	1.4		< %
					↙	↙	↙	↙	↙	↙	▲	↘	↘	↘	↘	↙	↙	↙	↙		<downhill arrow



east edge										0 - 2 ft			0 - 2 ft	2 - 4 ft	4 - 6 ft	6 - 8 ft	7 - 8 ft	8 - 10 ft	10 - 12 ft		
					18.3	17.6	17.9	18.4	17.7	16.5	-3.4	-1.1	-10.2	-10.8	-9.5	0.8	3.2	1.8	2.1		< %
					0.366	0.352	0.358	0.368	0.354	0.330		-0.022	-0.204	-0.216	-0.190	0.016	0.064	0.036	0.042		
					↙	↙	↙	↙	↙	↙	↘	↘	↘	↘	↘	↘	↙	↙	↙		<downhill arrow



13.5%   -0.4%

13.9% crest

< this is the side toward PRIVATE PROPERTY

south side of

Address + Street name: Sapphire & Goldrush Dr

Driveway is in this city, state: Fayetteville, AR

Land use type: apt

Land use abbreviations:

apt = apartment com = commercial

SF res = single-family residential

This form is set up for you to face **toward** oncoming vehicles on the through street.

Name : Ellis

Date measured : Aug 10, 2007

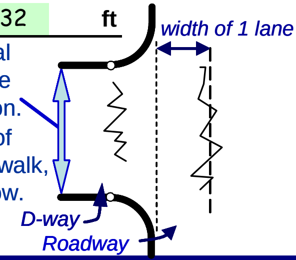
Set the horizontal position of the high or low point 0.0 here ↓

☒ Crest Sag ☒

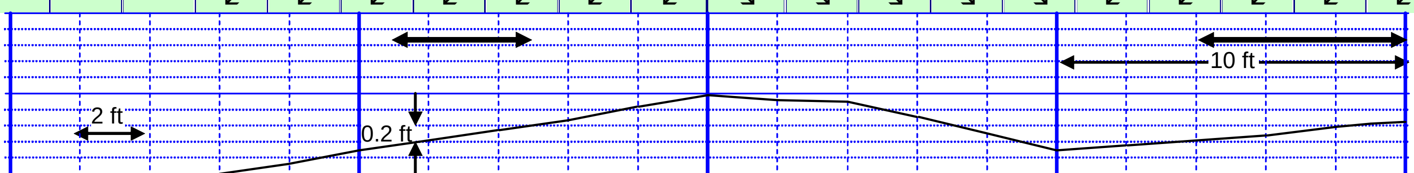
this is the side toward the ROADWAY >

D-way width: 32 **ft**

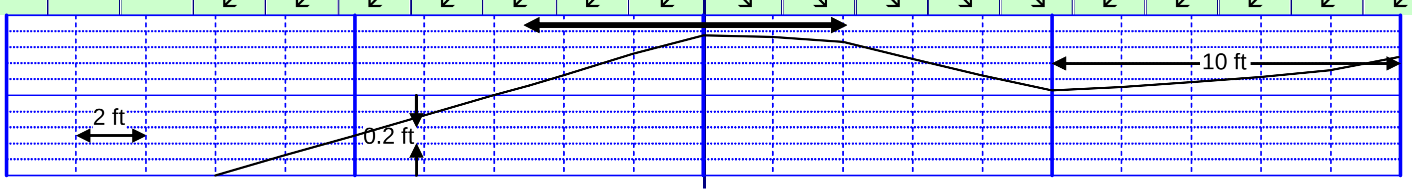
Measure the typical width of the surface available to drive on. Draw the location of gouge marks, sidewalk, islands, and N arrow.



Label which side of the d way: e.g., "south edge" ↓	18 - 20 ft	16 - 18 ft	14 - 16 ft	12 - 14 ft	10 - 12 ft	8 - 10 ft	6 - 8 ft	4 - 6 ft	2 - 4 ft	0 - 2 ft	0 - 2 ft	2 - 4 ft	4 - 6 ft	6 - 8 ft	8 - 10 ft	10 - 12 ft	12 - 14 ft	14 - 16 ft	16 - 18 ft	18 - 20 ft	< the 2 ft. increments
	① ENTER the % grade for the 2 ft or other increment; ② draw arrow to indicate slope; ③ draw the profile w/ scrape marks located.																				
West Edge							scrape											scrape	scrape	scrape	
				6.9	7.6	6.7	6.6	6.3	8.0	6.9	-2.9	-1.1	**-9.0**	**-9.6**	**-10.1**	**3.0**	**2.8**	**3.3**	4.3	3.1	< %
Radius ? 25 ft	0.000	0.000	0.000	0.138	0.152	0.134	0.132	0.126	0.160	0.138	-0.058	-0.022	-0.180	-0.192	-0.202	0.060	0.056	0.066	0.086	0.062	
				0.14	0.29	0.42	0.56	0.68	0.84	0.98	0.92	0.90	0.72	0.53	0.33	0.39	0.44	0.51	0.59	0.66	
				↙	↙	↙	↙	↙	↙	↙	↘	↘	↘	↘	↘	↙	↙	↙	↙	↙	<downhill arrow



	18 - 20 ft	16 - 18 ft	14 - 16 ft	12 - 14 ft	10 - 12 ft	8 - 10 ft	6 - 8 ft	4 - 6 ft	2 - 4 ft	0 - 2 ft	0 - 2 ft	2 - 4 ft	4 - 6 ft	6 - 8 ft	8 - 10 ft	10 - 12 ft	12 - 14 ft	14 - 16 ft	16 - 18 ft	18 - 20 ft	
East Edge									scrape	scrape	scrape	scrape						scrape	scrape	scrape	
				13.1	12.4	12.9	12.3	**12.7**	**13.5**	**10.7**	**-0.7**	**-3.1**	-11.4	-10.0	-9.4	1.7	2.8	2.7	3.3	3.3	< %
Radius ? 20 ft	0.000	0.000	0.000	0.262	0.248	0.258	0.246	0.254	0.270	0.214	-0.014	-0.062	-0.228	-0.200	-0.188	0.034	0.056	0.054	0.066	0.066	
				0.26	0.51	0.77	1.01	1.27	1.54	1.75	1.74	1.68	1.45	1.25	1.06	1.09	1.15	1.20	1.27	1.34	
				↙	↙	↙	↙	↙	↙	↙	↘	↘	↘	↘	↘	↙	↙	↙	↙	↙	<downhill arrow



12.3 1.9 9.6 3.0

crest 10.4% **-6.5% sag**

< this is the side toward PRIVATE PROPERTY

This form is set up for you to face **toward** oncoming vehicles on the through street.

this is the side toward the ROADWAY >

Address + Street name: Sixth St. east of S. School
Driveway is in this city, state: Fayetteville, AR
Land use type: com - O'reilly's Auto Parts

Land use abbreviations:
Apt = apartment Com = commercial
SF Res = single-family residential

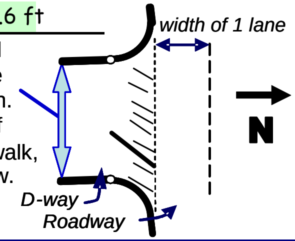
Name : Braddy,Reynolds,Reese
Date measured : May 22, 2008

Set the curb face at 0.0 here ↓

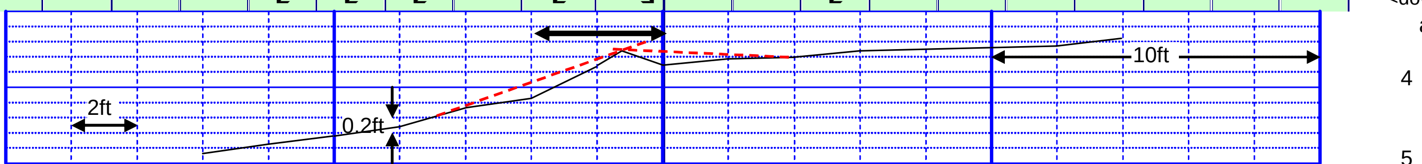
☒ Crest Sag ⚐

D-way width: 39.6 ft

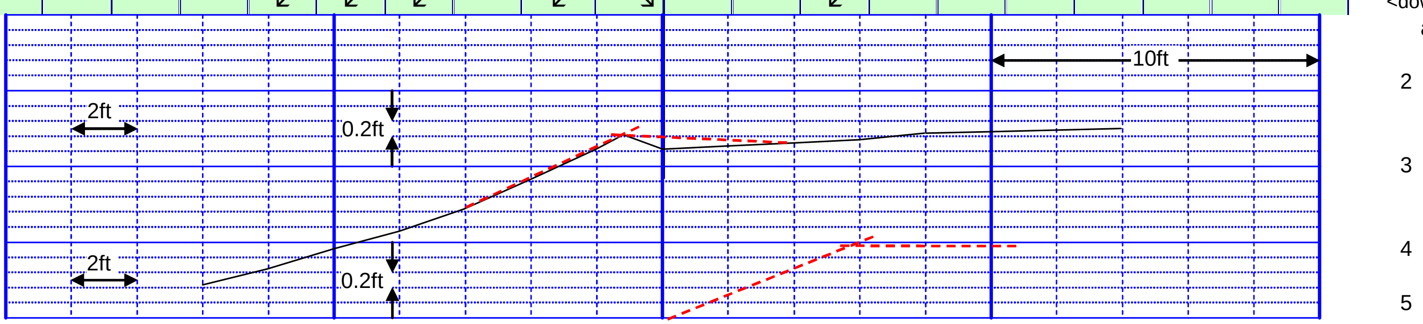
Measure the typical width of the surface available to drive on. Draw the location of gouge marks, sidewalk, islands, and N arrow.



Label which side of the d-way: e.g., "south edge" ↓	18 - 20 ft	16 - 18 ft	14 - 16 ft	12 - 14 ft	10 - 12 ft	8 - 10 ft	6 - 8 ft	4 - 6 ft	2 - 4 ft	0 - 2 ft	0 - 2 ft	2 - 4 ft	4 - 6 ft	6 - 8 ft	8 - 10 ft	10 - 12 ft	12 - 14 ft	14 - 16 ft	16 - 18 ft	18 - 20 ft	< the 2 ft. increments
									<scrape 4 - 0 >												
W edge (entry)		14	12	10	8	6	4	2	.8	0	2	4	6	8	10	12	14				
		4.89	4.77	4.65	4.56	4.34	4.18	3.74	3.52	3.71	3.61	3.60	3.52	3.48	3.47	3.46	3.39				
			0.060	0.060	0.045	0.110	0.080	0.220	0.183	-0.238	0.050	0.005	0.040	0.020	0.005	0.005	0.035				< %
					↙	↙	↙		↙	↘			↙								<downhill arrow



	18 - 20 ft	16 - 18 ft	14 - 16 ft	12 - 14 ft	10 - 12 ft	8 - 10 ft	6 - 8 ft	4 - 6 ft	2 - 4 ft	0 - 2 ft	0 - 2 ft	2 - 4 ft	4 - 6 ft	6 - 8 ft	8 - 10 ft	10 - 12 ft	12 - 14 ft	14 - 16 ft	16 - 18 ft	18 - 20 ft	
E edge (exit)		14	12	10	8	6	4	2	.8	0	2	4	6	8	10	12	14				
		4.58	4.38	4.13	3.86	3.59	3.18	2.79	2.59	2.79	2.75	2.69	2.64	2.57	2.55	2.52	2.53				
			0.100	0.125	0.135	0.135	0.205	0.195	0.167	-0.250	0.020	0.030	0.025	0.035	0.010	0.015	-0.005				< %
					↙	↙	↙		↙	↘			↙								<downhill arrow



effective crest Δ = **16.5%**

< this is the side toward PRIVATE PROPERTY

Address + Street name: 6 W. Sunbridge
Driveway is in this city, state: Fayetteville, AR
Land use type: com - Arthritis Center

Land use abbreviations:
apt = apartment com = commercial
SF res = single-family residential

This form is set up for you to face **toward** oncoming vehicles on the through street.
Name : Braddy,Reese,Reynolds
Date measured : June 2, 2008

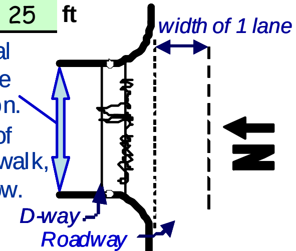
Set the curb face at 0.0 here ↓

☒ Crest Sag ®

this is the side toward the ROADWAY >

D-way width: 25 **ft**

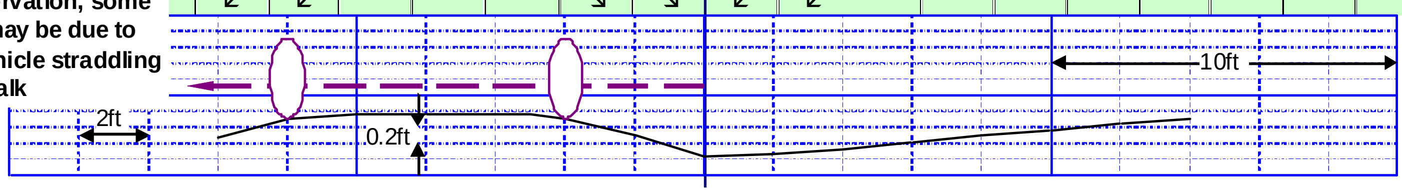
Measure the typical width of the surface available to drive on.
Draw the location of gouge marks, sidewalk, islands, and N arrow.



Label which side of the d-way: e.g., "south edge" ↓	18 - 20 ft	16 - 18 ft	14 - 16 ft	12 - 14 ft	10 - 12 ft	8 - 10 ft	6 - 8 ft	4 - 6 ft	2 - 4 ft	0 - 2 ft	0 - 2 ft	2 - 4 ft	4 - 6 ft	6 - 8 ft	8 - 10 ft	10 - 12 ft	12 - 14 ft	14 - 16 ft	16 - 18 ft	18 - 20 ft	< the 2 ft. increments
							slight scrape ‹ -- 10 - 3.5 -- ›														
W edge (exit)	14	12	10	**9.8**	8	6	**4.9**	4	2	**0**	2	4	6	8	10	12	14				
	5.85	5.68	5.51	5.50	5.49	5.47	5.46	5.53	5.82	6.06	5.99	5.91	5.83	5.74	5.66	5.59	5.52				
		0.085	0.085	0.050	0.006	0.010	0.009	-0.078	-0.145	-0.120	0.035	0.040	0.040	0.045	0.040	0.035	0.035				< %
				↙	↙				↘	↘	↙	↙									<downhill arrow

E edge (entry)	14	12	10	9.8	8	6	4.9	4	2	0	2	4	6	8	10	12	14				
	5.55	5.34	5.21	5.20	5.21	5.21	5.21	5.25	5.53	5.79	5.73	5.67	5.60	5.51	5.44	5.37	5.31				
		0.105	0.065	0.050	-0.006	0.000	0.000	-0.044	-0.140	-0.130	0.030	0.030	0.035	0.045	0.035	0.035	0.030				< %
				↙	↙				↘	↘	↙	↙									<downhill arrow

from observation, some scrapes may be due to longer vehicle straddling the sidewalk



9.8 4.9 0
5.5 5.46 6.06
0.8% 12.2%
13.1% crest

< this is the side toward PRIVATE PROPERTY

This form is set up for you to face **toward** oncoming vehicles on the through street.

this is the side toward the ROADWAY >

Address + Street name: 18 E. Sunbridge
Driveway is in this city, state: Fayetteville, AR
Land use type: com - McLellans Fly Shop

Land use abbreviations:
apt = apartment   com = commercial
SF res = single-family residential

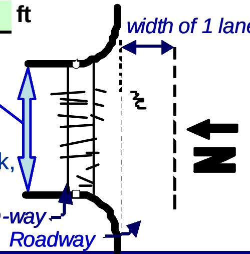
Name : Braddy,Reese,Reynolds
Date measured : June 2, 2008

Set the curb face at 0.0 here ↓

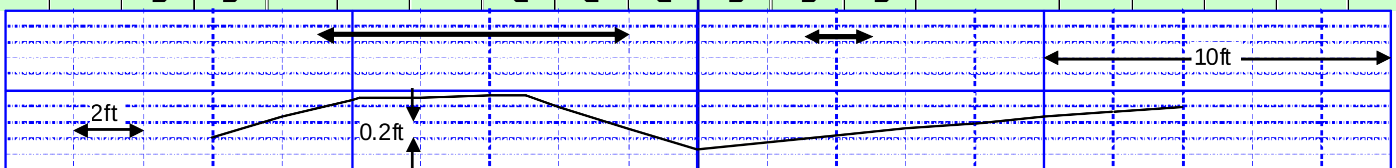
☒ Crest   Sag ☒

D-way width: 25 **ft**

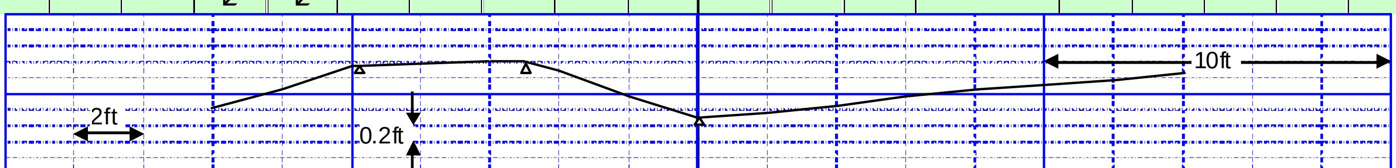
Measure the typical width of the surface available to drive on.
Draw the location of gouge marks, sidewalk, islands, and N arrow.



Label which side of the d-way: e.g., "south edge" ↓	18 - 20 ft	16 - 18 ft	14 - 16 ft	12 - 14 ft	10 - 12 ft	8 - 10 ft	6 - 8 ft	4 - 6 ft	2 - 4 ft	0 - 2 ft	0 - 2 ft	2 - 4 ft	4 - 6 ft	6 - 8 ft	8 - 10 ft	10 - 12 ft	12 - 14 ft	14 - 16 ft	16 - 18 ft	18 - 20 ft	< the 2 ft. increments
					< --- severe scrape 11 - 2 --->							scrape < 3 - 5 >									
E edge	14	12	10	9.6	8	6	5	4	2	0	2	4	6	8	10	12	14				
	5.58	5.32	5.11	5.08	5.07	5.06	5.05	5.20	5.46	5.74	5.64	5.58	5.49	5.41	5.35	5.28	5.21				
		0.130	0.105	0.075	0.006	0.005	0.010	-0.150	-0.130	-0.140	0.050	0.030	0.045	0.040	0.030	0.035	0.035				< %
			↙	↙				↘	↘	↘	↙	↙	↙								<downhill arrow



	18 - 20 ft	16 - 18 ft	14 - 16 ft	12 - 14 ft	10 - 12 ft	8 - 10 ft	6 - 8 ft	4 - 6 ft	2 - 4 ft	0 - 2 ft	0 - 2 ft	2 - 4 ft	4 - 6 ft	6 - 8 ft	8 - 10 ft	10 - 12 ft	12 - 14 ft	14 - 16 ft	16 - 18 ft	18 - 20 ft	
W edge	14	12	10	**9.6**	8	6	**5**	4	2	**0**	2	4	6	8	10	12	14				
	6.18	5.95	5.68	5.65	5.63	5.62	5.62	5.72	6.02	6.29	6.21	6.16	6.06	5.98	5.91	5.83	5.75				
		0.115	0.135	0.075	0.013	0.005	0.000	-0.100	-0.150	-0.135	0.040	0.025	0.050	0.040	0.035	0.040	0.040				< %
				↙	↙																<downhill arrow



14	9.6	5	0	6
6.18	5.65	5.62	6.29	6.06

12.0%   0.7%   -13.4%   3.8%

crest 11.4%   crest 14.1%   **17.2% sag**

< this is the side toward PRIVATE PROPERTY

Address + Street name: 114 E. Sunbridge
Driveway is in this city, state: Fayetteville, AR
Land use type: com - Sunbridge Center

Land use abbreviations:
apt = apartment   com = commercial
SF res = single-family residential

This form is set up for you to face **toward** oncoming vehicles on the through street.

Name : Braddy,Reese,Reynolds
Date measured : June 2, 2008

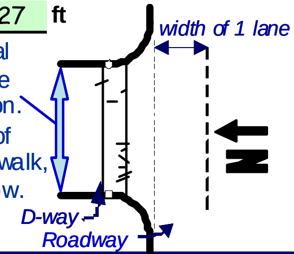
Set the curb face at 0.0 here ↓

☒ Crest   Sag ❺

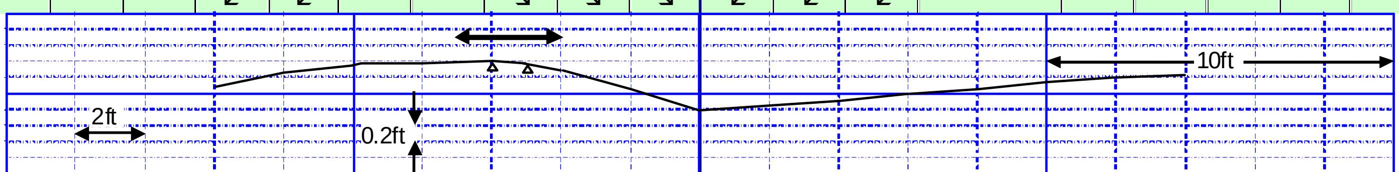
this is the side toward the ROADWAY >

D-way width: 27 **ft**

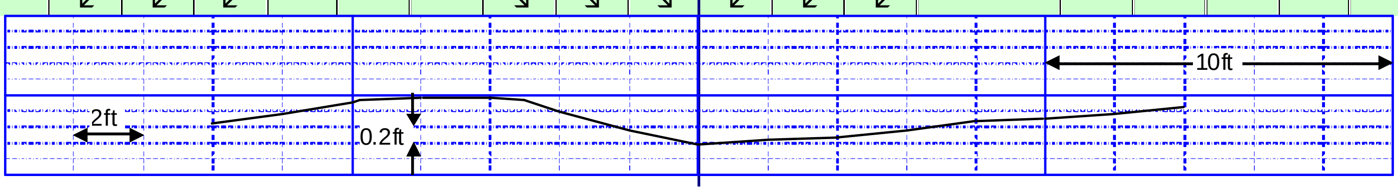
Measure the typical width of the surface available to drive on.
Draw the location of gouge marks, sidewalk, islands, and N arrow.



Label which side of the d-way: e.g., "south edge" ↓	18 - 20 ft	16 - 18 ft	14 - 16 ft	12 - 14 ft	10 - 12 ft	8 - 10 ft	6 - 8 ft	4 - 6 ft	2 - 4 ft	0 - 2 ft	0 - 2 ft	2 - 4 ft	4 - 6 ft	6 - 8 ft	8 - 10 ft	10 - 12 ft	12 - 14 ft	14 - 16 ft	16 - 18 ft	18 - 20 ft	< the 2 ft. increments
								slight <scrape 7-4>													
E edge	14	12	10	**9.7**	8	6	**5.1**	4	2	**0**	2	4	6	8	10	12	14				
	4.92	4.76	4.63	4.62	4.62	4.60	4.61	4.73	4.93	5.21	5.16	5.11	5.03	4.95	4.88	4.81	4.76				
		0.080	0.065	0.033	0.000	0.010	-0.011	-0.109	-0.100	-0.140	0.025	0.025	0.040	0.040	0.035	0.035	0.025				< %
				↙	↙			↘	↘	↘	↙	↙	↙								<downhill arrow



	18 - 20 ft	16 - 18 ft	14 - 16 ft	12 - 14 ft	10 - 12 ft	8 - 10 ft	6 - 8 ft	4 - 6 ft	2 - 4 ft	0 - 2 ft	0 - 2 ft	2 - 4 ft	4 - 6 ft	6 - 8 ft	8 - 10 ft	10 - 12 ft	12 - 14 ft	14 - 16 ft	16 - 18 ft	18 - 20 ft	
W edge	14	12	10	9.7	8	6	5.1	4	2	0	2	4	6	8	10	12	14				
	5.37	5.23	5.07	5.05	5.03	5.03	5.05	5.20	5.43	5.63	5.58	5.54	5.45	5.36	5.31	5.23	5.18				
		0.070	0.080	0.067	0.012	0.000	-0.022	-0.136	-0.115	-0.100	0.025	0.020	0.045	0.045	0.025	0.040	0.025				< %
		↙	↙	↙				↘	↘	↘	↙	↙	↙								<downhill arrow



9.7		5.1		0
4.62		4.61		5.21
	0.2%		-11.8%	
	crest 12.0%			

< this is the side toward PRIVATE PROPERTY

Address + Street name: 158 E. Sunbridge
Driveway is in this city, state: Fayetteville, AR
Land use type: com - VA Dental

Land use abbreviations:
apt = apartment com = commercial
SF res = single-family residential

This form is set up for you to face **toward** oncoming vehicles on the through street.

Name : Braddy,Reese,Reynolds
Date measured : June 2, 2008

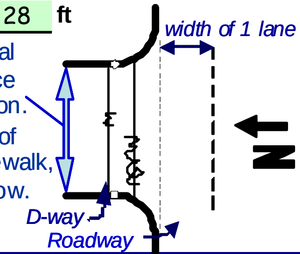
Set the curb face at 0.0 here ↓

☒ Crest Sag ☒

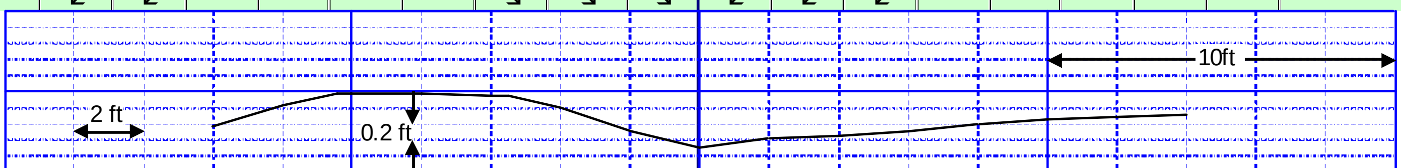
this is the side toward the ROADWAY >

D-way width: 28 **ft**

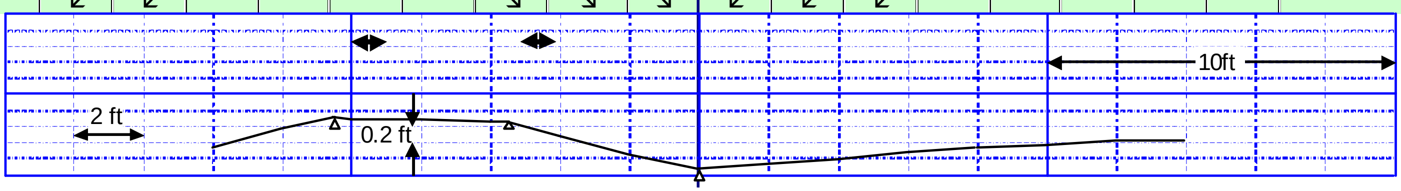
Measure the typical width of the surface available to drive on.
Draw the location of gouge marks, sidewalk, islands, and N arrow.



Label which side of the d-way: e.g., "south edge" ↓	18 - 20 ft	16 - 18 ft	14 - 16 ft	12 - 14 ft	10 - 12 ft	8 - 10 ft	6 - 8 ft	4 - 6 ft	2 - 4 ft	0 - 2 ft	0 - 2 ft	2 - 4 ft	4 - 6 ft	6 - 8 ft	8 - 10 ft	10 - 12 ft	12 - 14 ft	14 - 16 ft	16 - 18 ft	18 - 20 ft	< the 2 ft. increments
						slight scrapes 10-9		5-4													
E edge (entry)	14	12	10.5	10	8	6	5.5	4	2	0	2	4	6	8	10	12	14				
	6.43	6.19	6.01	6.01	6.01	6.05	6.05	6.20	6.46	6.65	6.58	6.53	6.46	6.41	6.37	6.32	6.29				
		0.120	0.120	0.000	0.000	-0.020	0.000	-0.100	-0.130	-0.095	0.035	0.025	0.035	0.025	0.020	0.025	0.015				< %
		↙	↙					↘	↘	↘	↙	↙	↙								<downhill arrow



	18 - 20 ft	16 - 18 ft	14 - 16 ft	12 - 14 ft	10 - 12 ft	8 - 10 ft	6 - 8 ft	4 - 6 ft	2 - 4 ft	0 - 2 ft	0 - 2 ft	2 - 4 ft	4 - 6 ft	6 - 8 ft	8 - 10 ft	10 - 12 ft	12 - 14 ft	14 - 16 ft	16 - 18 ft	18 - 20 ft	
W edge (exit)	**14**	12	**10.5**	10	8	6	**5.5**	4	2	**0**	2	4	**6**	8	10	12	14				
	6.64	6.42	6.29	6.30	6.32	6.34	6.34	6.52	6.77	6.93	6.86	6.81	6.74	6.68	6.65	6.57	6.57				
		0.110	0.087	-0.020	-0.010	-0.010	0.000	-0.120	-0.125	-0.080	0.035	0.025	0.035	0.030	0.015	0.040	0.000				< %
		↙	↙					↘	↘	↘	↙	↙	↙								<downhill arrow



14	10.5	5.5	5.5	0	6
6.64	6.29	6.34	6.34	6.93	6.74

10.0% -1.0% -10.7% 3.2%

crest 11.0% crest 9.7% sag 13.9%

< this is the side toward PRIVATE PROPERTY

Address + Street name: 180 E. Sunbridge
Driveway is in this city, state: Fayetteville, AR
Land use type: com -VA Outpatient

Land use abbreviations:
apt = apartment   com = commercial
SF res = single-family residential

This form is set up for you to face **toward** oncoming vehicles on the through street.

Name : Braddy,Reese,Reynolds
Date measured : June 2, 2008

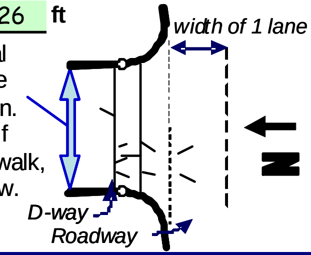
Set the curb face at 0.0 here ↓

☒ Crest   Sag ☒

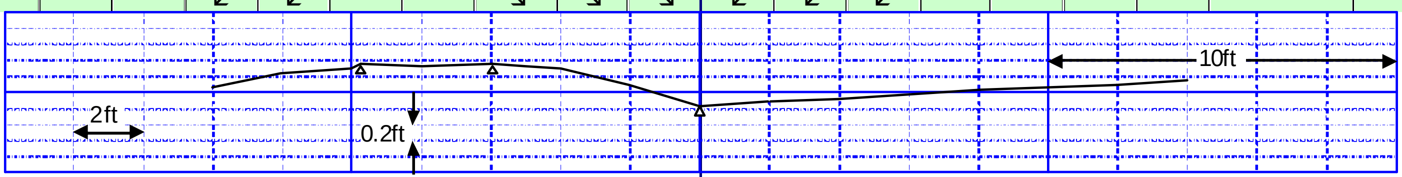
this is the side toward the ROADWAY >

D-way width: 26 **ft**

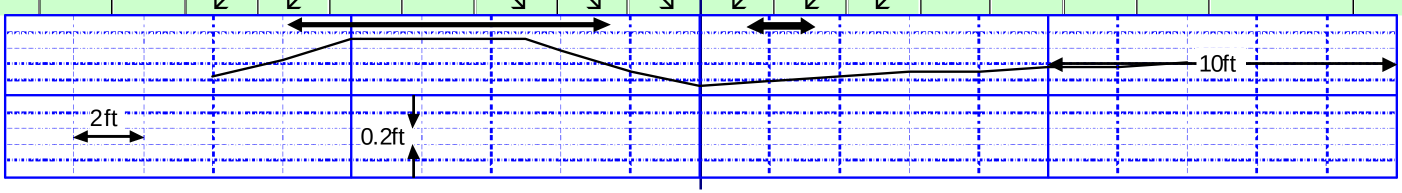
Measure the typical width of the surface available to drive on. Draw the location of gouge marks, sidewalk, islands, and N arrow.



Label which side of the d-way: e.g., "south edge" ↓	18 - 20 ft	16 - 18 ft	14 - 16 ft	12 - 14 ft	10 - 12 ft	8 - 10 ft	6 - 8 ft	4 - 6 ft	2 - 4 ft	0 - 2 ft	0 - 2 ft	2 - 4 ft	4 - 6 ft	6 - 8 ft	8 - 10 ft	10 - 12 ft	12 - 14 ft	14 - 16 ft	16 - 18 ft	18 - 20 ft	< the 2 ft. increments
					< slight scrape		12 - 3	>				slight scrape 1-3									
E edge (entry)	14	12	10	9.8	8	6	4.9	4	2	0	2	4	6	8	10	12	14				
	4.93	4.78	4.69	4.63	4.64	4.63	4.64	4.69	4.92	5.19	5.11	5.05	5.01	4.97	4.92	4.88	4.83				
		0.075	0.045	0.300	-0.006	0.005	-0.009	-0.056	-0.115	-0.135	0.040	0.030	0.020	0.020	0.025	0.020	0.025				< %
				↙	↙			↘	↘	↘	↙	↙	↙								<downhill arrow



W edge (exit)	14	12	10	9.8	8	6	4.9	4	2	0	2	4	6	8	10	12	14				
	4.78	4.54	4.33	4.32	4.32	4.33	4.33	4.43	4.68	4.89	4.80	4.75	4.71	4.68	4.63	4.61	4.58				
		0.120	0.105	0.050	0.000	-0.005	0.000	-0.111	-0.125	-0.105	0.045	0.025	0.020	0.015	0.025	0.010	0.015				< %
				↙	↙			↘	↘	↘	↙	↙	↙								<downhill arrow



9.8	4.9		0	0	6
4.63	4.64		5.19	5.19	5.01
0.2%		-11.2%		3.0%	
crest 11.4%		**sag** 14.2%			

< this is the side toward PRIVATE PROPERTY

This form is set up for you to face **toward** oncoming vehicles on the through street.

this is the side toward the ROADWAY >

D-way width: 23 **ft**

Address + Street name: E Sycamore St (W edge) 1680 N College   Name : Ellis

Driveway is in this city, state: Fayetteville, AR   Date measured : Aug 10, 2007

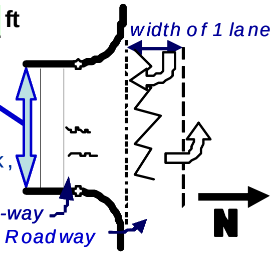
Land use type: com - Royal Cleaners

Land use abbreviations:
apt = apartment com = commercial
SF res = single-family residential

Set the curb face at 0.0 here ↓

☐ Crest   Sag ☒

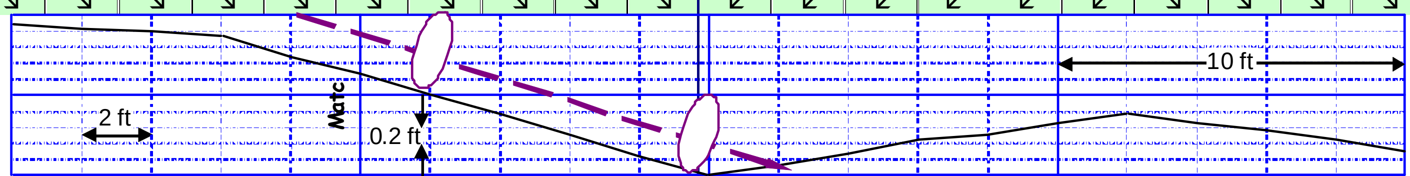
Measure the typical width of the surface available to drive on. Draw the location of gouge marks, sidewalk, islands, and N arrow.



Label which side of the d-way: e.g., "south edge" ↓

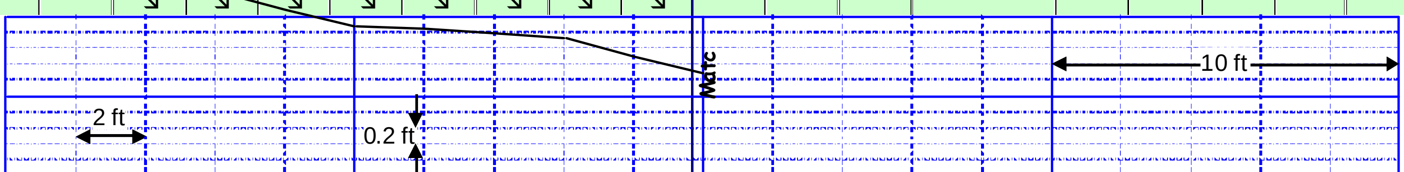
① ENTER the % grade for the 2 ft or other increment; ② draw arrow to indicate slope; ③ draw the profile w/ scrape marks located.

	18-20 ft	16-18 ft	14-16 ft	12-14 ft	10-12 ft	8-10 ft	6-8 ft	4-6 ft	2-4 ft	0-2 ft	0-2 ft	2-4 ft	4-6 ft	6-8 ft	8-10 ft	10-12 ft	12-14 ft	14-16 ft	16-18 ft	18-20 ft	< the 2 ft. increments
					<-- minor scrape 13 to 5 ft -->							<--- gouge 2 to 11 ft --->									
West Edge		<--- 6' sidewalk --->																			
	-2.1	-1.7	-2.6	-12.0	-10.3	-12.5	**-13.3**	**-13.6**	**-13.1**	**-13.1**	**5.7**	**6.8**	**7.8**	**4.7**	6.2	6.6	-5.2	-5.1	-5.9	-7.3	< %
Radius ?12 ft	-0.042	-0.034	-0.052	-0.240	-0.206	-0.250	-0.266	-0.272	-0.262	-0.262	0.114	0.136	0.156	0.094	0.124	0.132	-0.104	-0.102	-0.118	-0.146	
	1.89	1.84	1.81	1.76	1.52	1.31	1.06	0.80	0.52	0.26	0.11	0.25	0.41	0.50	0.62	0.76	0.65	0.55	0.43	0.29	
	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘	↙	↙	↙	↙	↙	↙	↘	↘	↘	↘	<downhill arrow



	18-20 ft	16-18 ft	14-16 ft	12-14 ft	10-12 ft	8-10 ft	6-8 ft	4-6 ft	2-4 ft	0-2 ft	0-2 ft	2-4 ft	4-6 ft	6-8 ft	8-10 ft	10-12 ft	12-14 ft	14-16 ft	16-18 ft	18-20 ft	
West Edge						<---sidewalk--->															
(cont'd			-8.4	-11.4	-10.1	-2.1	-1.7	-2.6	-12.0	-10.3											< %
toward			-0.168	-0.228	-0.202	-0.042	-0.034	-0.052	-0.240	-0.206											
private			2.48	2.32	2.09	1.89	1.84	1.81	1.76	1.52											
property)			↘	↘	↘	↘	↘	↘	↘	↘											<downhill arrow

observed front bumper scraping



-13.3%   6.3%

19.5% sag

< this is the side toward PRIVATE PROPERTY

Address + Street name: 2255 W. Sunset
Driveway is in this city, state: Springdale, AR
Land use type: com - Fuji Restaurant (west drive)

Land use abbreviations:
apt = apartment com = commercial
SF res = single-family residential

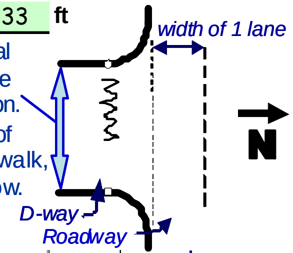
This form is set up for you to face **toward** oncoming vehicles on the through street.

Name : Gattis, Reese
Date measured : Oct 13, 2008

this is the side toward the ROADWAY >

D-way width: 33 **ft**

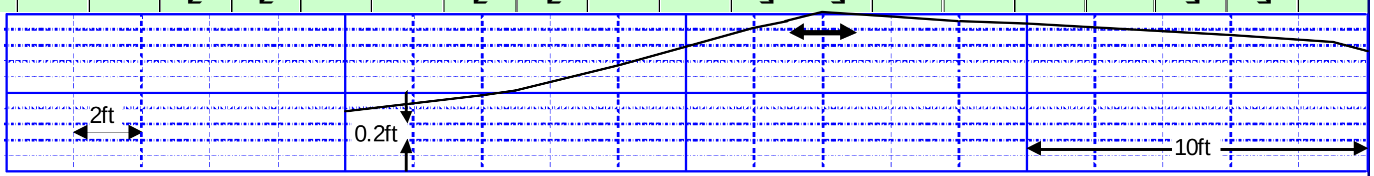
Measure the typical width of the surface available to drive on.
Draw the location of gouge marks, sidewalk, islands, and N arrow.



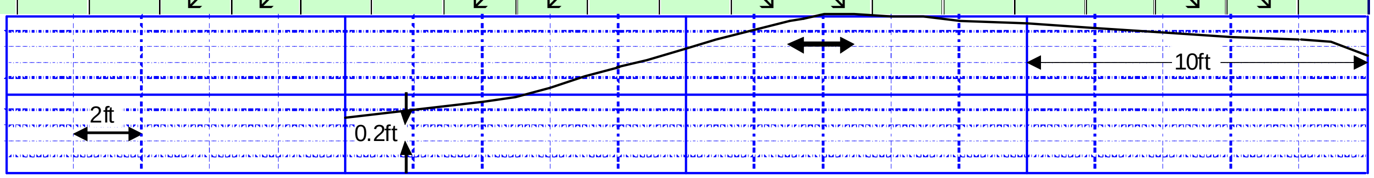
☒ Crest Sag ☐

many scrapes
<-- 17 - 15 -->

Label which side of the d-way ↓																				
18 ft from W edge	30	26	25	22	21	20	19	18	17	16.5	16	15.5	15	14	13	12	10	4	1	0
	6.21	6.04	5.98	5.63	5.51	5.41	5.30	5.18	5.07	5.02	4.99	5.00	5.01	5.02	5.05	5.09	5.14	5.28	5.36	5.45
< %		0.043	0.060	0.117	0.120	0.100	0.110	0.120	0.110	0.100	0.060	-0.020	-0.020	-0.010	-0.030	-0.040	-0.025	-0.023	-0.027	-0.090
< downhill arrow				↙	↙			↙	↙			↘	↘					↘	↘	



6 ft from W edge (entry)	30	26	25	22	21	20	19	18	17	16.5	16	15.5	15	14	13	12	10	4	1	0
	6.33	6.11	6.04	5.68	5.55	5.44	5.31	5.20	5.085	5.03	4.99	4.99	4.99	5.00	5.01	5.04	5.10	5.26	5.34	5.49
		0.055	0.070	0.120	0.130	0.110	0.130	0.110	0.115	0.110	0.080	0.000	0.000	-0.010	-0.010	-0.030	-0.030	-0.027	-0.027	-0.150
				↙	↙			↙	↙			↘	↘					↘	↘	



25	17	14	1
5.98	5.07	5.02	5.36
	11.4%	-2.6%	

14.0% crest with slight rounding

16 16
4.96 4.97 < extrapolated elev. from projected grades
-0.03 ft or -0.4 in. = rounding

< this is the side toward PRIVATE PROPERTY

Address + Street name: 6550 E 71st
Driveway is in this city, state: Tulsa, OK
Land use type: com - Arvest, Hausam

Land use abbreviations:
apt = apartment com = commercial
SF res = single-family residential

This form is set up for you to face **toward** oncoming vehicles on the through street.

Name : Braddy,Reese,Reynolds
Date measured : Aug 20, 2008

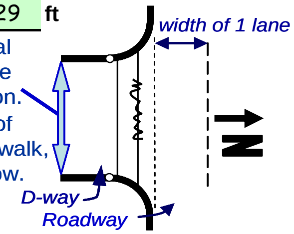
Set the curb face at 0.0 here ↓

☐ Crest Sag ☒

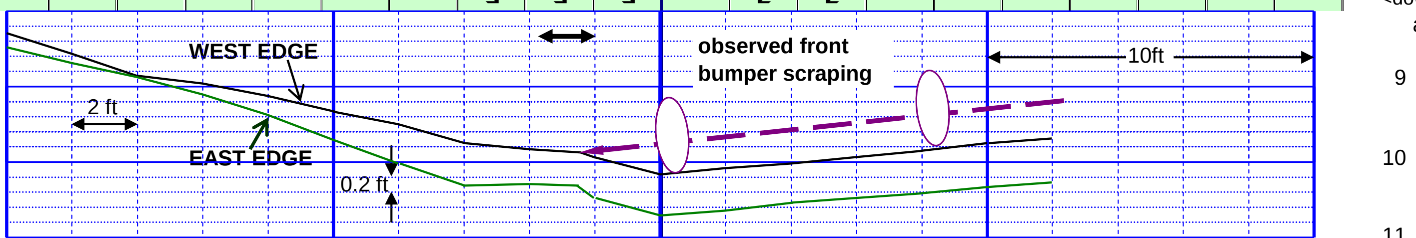
this is the side toward the ROADWAY >

D-way width: 29 **ft**

Measure the typical width of the surface available to drive on.
Draw the location of gouge marks, sidewalk, islands, and N arrow.



Label which side of the d-way: e.g., "south edge" ↓											0 - 2 ft	0 - 2 ft	2 - 4 ft	4 - 6 ft	6 - 8 ft	8 - 10 ft	10 - 12 ft	12 - 14 ft	14 - 16 ft	16 - 18 ft	18 - 20 ft	< the 2 ft. increments
									scrape 3.5-2													
WEST (entry)	20	18	16	14	12	10	8	6	4	2.5	2	0	2	4	6	8	10	12				
	8.29	8.58	8.84	8.96	9.14	9.34	9.55	9.75	9.81	9.87	9.94	10.18	10.08	10.01	9.94	9.86	9.78	9.69				
		-0.145	-0.130	-0.060	-0.090	-0.100	-0.105	-0.100	-0.030	-0.040	-0.140	-0.120	0.050	0.035	0.035	0.040	0.040	0.045				< %
										↘	↘	↘		↙	↙							<downhill arrow



EAST (exit)	20	18	16	14	12	10	8	6	4	2.5	2	0	2	4	6	8	10	12				
	8.49	8.67	8.88	9.08	9.39	9.71	10.01	10.32	10.31	10.32	10.48	10.70	10.63	10.56	10.49	10.41	10.33	10.26				
		-0.090	-0.105	-0.100	-0.155	-0.160	-0.150	-0.155	0.005	-0.007	-0.320	-0.110	0.035	0.035	0.035	0.040	0.040	0.035				< %
										↘	↘	↘					↙	↙				<downhill arrow

6		2.5		0			6
9.75		9.87		10.18			9.94
	-3.4%		-12.4%			4.0%	
	crest	9.0%			16.4%	**sag**	

< this is the side toward PRIVATE PROPERTY

This form is set up for you to face **toward** oncoming vehicles on the through street.

this is the side toward the ROADWAY >

D-way width: 29.3 **ft**

Address + Street name: 6616 E. Archer

Driveway is in this city, state: Tulsa, OK

Land use type: com - Super 8 motel

Land use abbreviations:

apt = apartment com = commercial

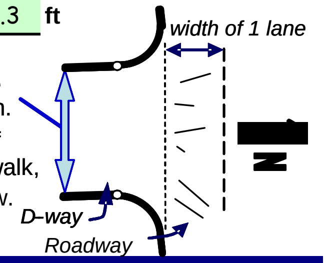
SF res = single-family residential

Name : Gattis

Date measured : March 15, 2008

Measure the typical width of the surface available to drive on.

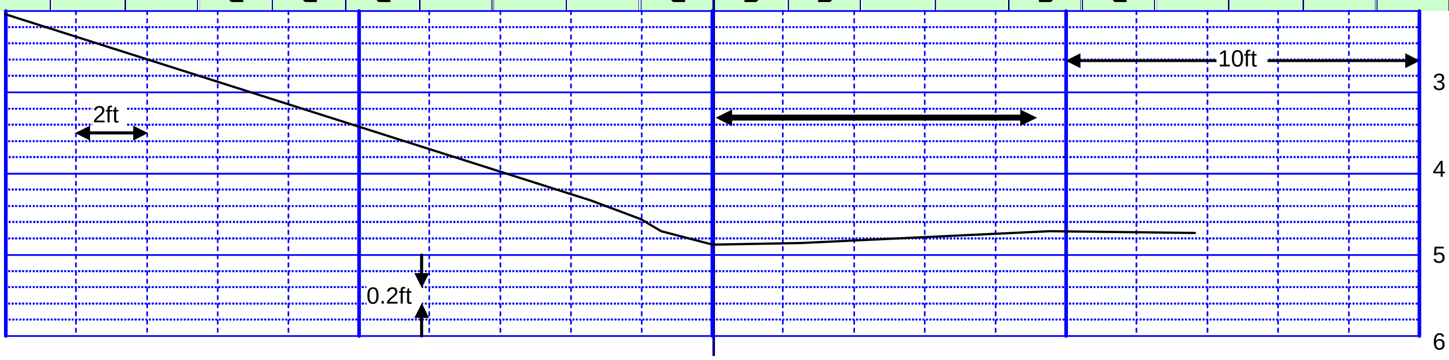
Draw the location of gouge marks, sidewalk, islands, and N arrow.



Set the horizontal position of the high or low point 0.0 here ↓

☐ Crest Sag ☒

Label which side of the d way: e.g., "south edge" ↓	18 - 20 ft	16 - 18 ft	14 - 16 ft	12 - 14 ft	10 - 12 ft	8 - 10 ft	6 - 8 ft	4 - 6 ft	2 - 4 ft	0 - 2 ft	0 - 2 ft	2 - 4 ft	4 - 6 ft	6 - 8 ft	8 - 10 ft	10 - 12 ft	12 - 14 ft	14 - 16 ft	16 - 18 ft	18 - 20 ft	< the 2 ft. increments
											< scrape 0 - 9 >										
	20						3.5	2.0	1.5	0	2.5				9.5		13.5				
	2.02						4.36	4.59	4.69	4.86	4.85				4.73		4.74				
				-0.142				-0.153	-0.200	-0.113	0.004	0.017				-0.002					< %
				↘	↘	↘				↘	↙	↙			↙	↘					<downhill arrow



	6	1.5	2.5	9.5
calculated	4.005	4.69	4.85	4.73

-15.2% 1.7%

16.9% sag

< this is the side toward PRIVATE PROPERTY

Address + Street name: east side of Mingo north of E 71st
Driveway is in this city, state: Tulsa, OK
Land use type: com - Union Plaza

Land use abbreviations:
apt = apartment com = commercial
SF res = single-family residential

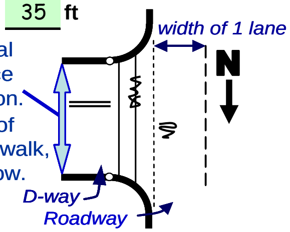
This form is set up for you to face **toward** oncoming vehicles on the through street.
Name : Braddy,Reese,Reynolds
Date measured : Aug 20, 2008

Set the curb face at 0.0 here ↓

☒ Crest   Sag ☒

this is the side toward the ROADWAY >
D-way width: 35 **ft**

Measure the typical width of the surface available to drive on.
Draw the location of gouge marks, sidewalk, islands, and N arrow.

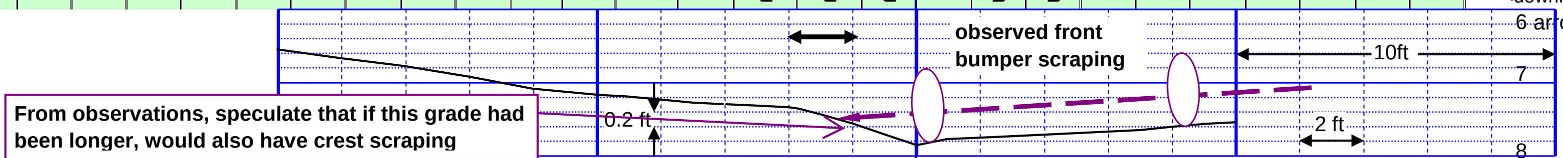


Label which side of the d. way: e.g., "south edge" ↓

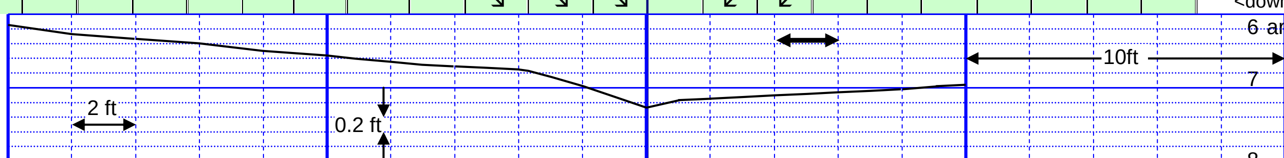
< the 2 ft. increments

scrape 4-2   scrape 4-6

South (entry)	20	18	16	14	12	10	**9**	8	7	6	5	4	**3.8**	3	2	1	**0**	1	2	3	4	5	**6**	7	8	9	10	
	6.56	6.67	6.79	6.93	7.08	7.15	7.19	7.23	7.27	7.29	7.30	7.33	7.34	7.42	7.56	7.73	7.85	7.78	7.74	7.72	7.69	7.67	7.65	7.63	7.60	7.58	7.55	
		-0.055	-0.060	-0.070	-0.075	-0.035	-0.040	-0.040	-0.040	-0.020	-0.010	-0.030	-0.050	-0.100	-0.140	-0.170	-0.120	0.070	0.040	0.020	0.030	0.020	0.020	0.020	0.030	0.020	0.030	< %
															↘	↘	↘		↙	↙								<downhill arrow



North (exit)	20	18	16	14	12	10	9	8	7	6	5	4	3.8	3	2	1	0	1	2	3	4	5	6	7	8	9	10	
	6.15	6.25	6.33	6.40	6.48	6.57	6.61	6.64	6.67	6.70	6.73	6.76	6.79	6.88	6.99	7.13	7.26	7.19	7.15	7.11	7.09	7.08	7.05	7.02	7.01	6.98	6.96	
		-0.050	-0.040	-0.035	-0.040	-0.045	-0.040	-0.030	-0.030	-0.030	-0.030	-0.030	-0.150	-0.113	-0.110	-0.140	-0.130	0.070	0.040	0.040	0.020	0.010	0.030	0.030	0.010	0.030	0.020	< %
															↘	↘	↘		↙	↙								<downhill arrow



9		3.8		0		6	
7.19		7.34		7.85		7.65	
	-2.9%		-13.4%		3.3%		
crest	10.5%		16.8%	sag			

APPENDIX G

Photographs of the Speed Study Sites

This appendix presents photographs taken of the sites at which speeds and elapsed travel times of vehicles turning left and right into driveways were measured.

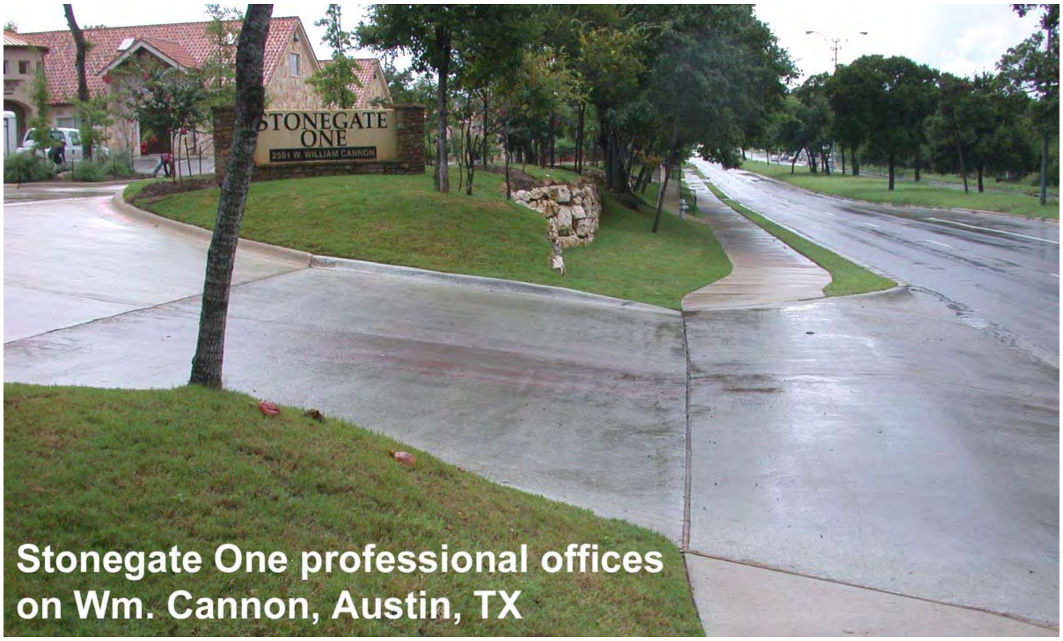


EXHIBIT G-1 Steeper driveway site, Stonegate

EXHIBIT G-2 Steeper driveway site, Genie

EXHIBIT G-3 Steeper driveway site, Union Plaza

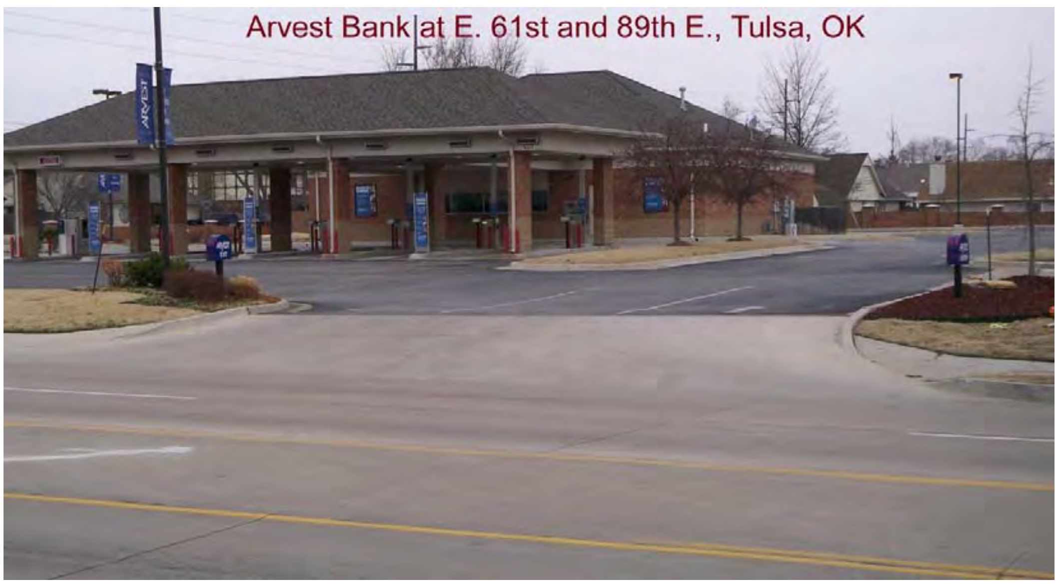


EXHIBIT G-4 Steeper driveway site, Arvest

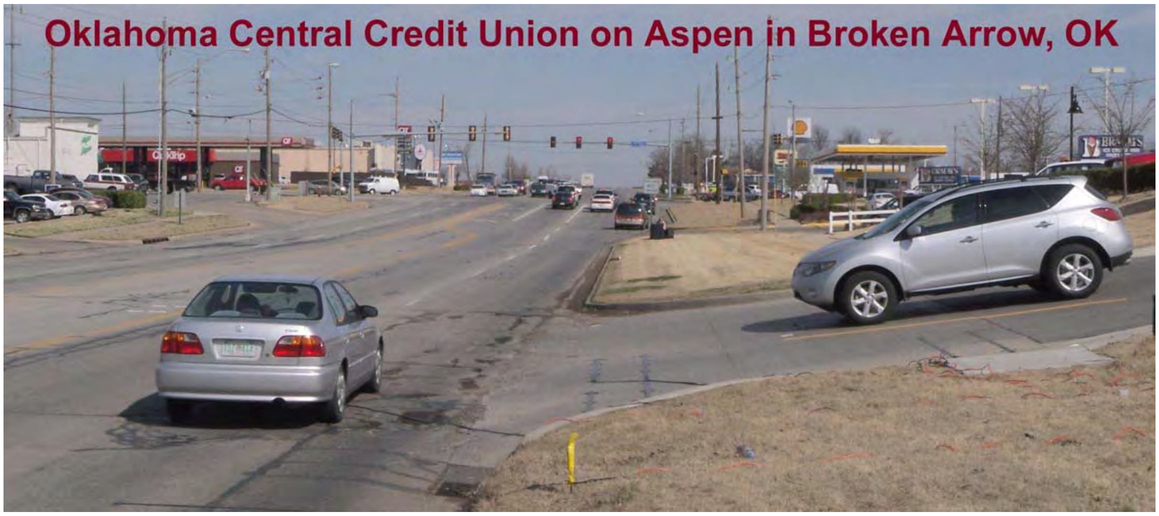


EXHIBIT G-5 Moderate driveway site, Oklahoma Central

.

EXHIBIT G-6 Moderate driveway site, McAlister's

EXHIBIT G-7 Moderate driveway site, HEB

EXHIBIT G-8 Moderate driveway site, Hollywood

EXHIBIT G-9 Flatter driveway site, Wendy’s

EXHIBIT G-10 Flatter driveway site, J. D. China

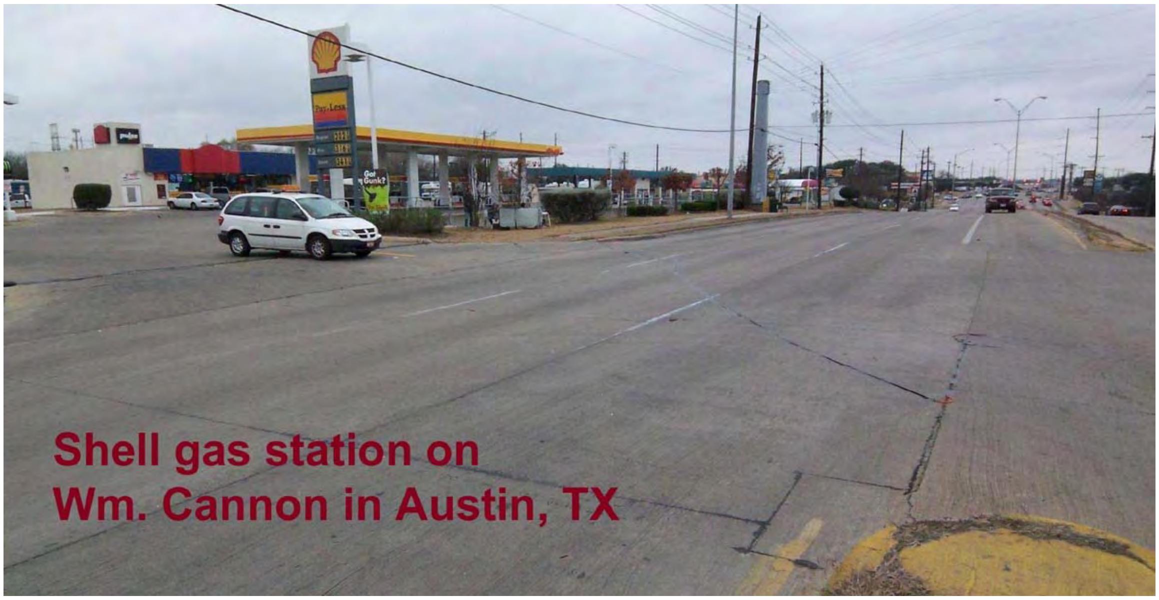


EXHIBIT G-11 Flatter driveway site, Shell

EXHIBIT G-12 Flatter driveway site, Red Robin