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**DRIVEWAY DESIGN PRACTICES, ISSUES, AND NEEDS**

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**ABSTRACT**

Driveways are an important and growing component of highway transportation systems. They have grown in number and complexity as urbanized areas have expanded. This paper traces their development and identifies key geometric issues and elements. It presents the salient results of a comprehensive agency-practice survey and literature review. Finally, it suggests possible areas for further research. A key finding is to design driveways in a multi-modal context that provides for safe and convenient movement by motor vehicles, bicycles, and pedestrians.

## **DRIVEWAY DESIGN PRACTICES, ISSUES, AND NEEDS**

By Herbert S. Levinson and Jerome S. Gluck

### **INTRODUCTION**

Driveways are private roads that provide access between a public way and abutting properties, including the buildings and activities on these properties. Since they connect the public street or highway with the activities they serve, driveways are an integral part of the highway-based transportation system.

Driveways are ubiquitous. They are found in urban, rural, and suburban areas. They are located along highways (i.e. non-access controlled), suburban roadways, city streets and alleys. They vary in design based on activity served, development density, types of vehicles served, proximity to intersections, and exposure to pedestrians and bicyclists. Where they are located and how well they are designed affect the safety and mobility of vehicles and pedestrians and may influence the quality of the adjacent roadside development. They have evolved over the years, as land development patterns have changed.

There has been less study of driveways as compared with other types of roadway facilities. Comprehensive guidance has been mainly limited to the AASHTO (1) and ITE (2) guidelines, published in 1959 and 1987, respectively, and to the more recent Access Management Manual (3) and the U.S. Access Board's Draft Guidelines (4) published in 2005. The increased emphasis on multi-modal considerations and ADA requirements, called for another look at driveway design.

Accordingly, NCHRP Project 15-35 "Geometric Design of Driveways" was initiated in 2006 to develop recommendations for the geometric design of driveways. The first phase, documented in a draft interim report (5), reviews the literature and current practices, identifies key geometric elements, and suggests research possibilities.

This paper draws and builds upon the interim materials. It traces the changing perspectives associated with driveway design and reviews the state of current practice. It identifies key issues and challenges, and suggests possible direction for further research.

### **EVOLVING DEVELOPMENT**

Driveway design practices and perspectives have changed over the past century. These changes reflect growing car ownership and travel, urban decentralization, emerging municipal zoning and subdivision requirements, and geometric design standards. More recently, there has been greater emphasis on managing access and meeting the needs of the mobility impaired.

The first "driveways" were farm access connections to public roadways in the 19th century. They were followed by driveways serving carriage houses of large estates or homes, often in suburban settings. Service stations emerged in the early 1900s to serve motor vehicles. Zoning laws and subdivisions requirements date back to the 1920s.

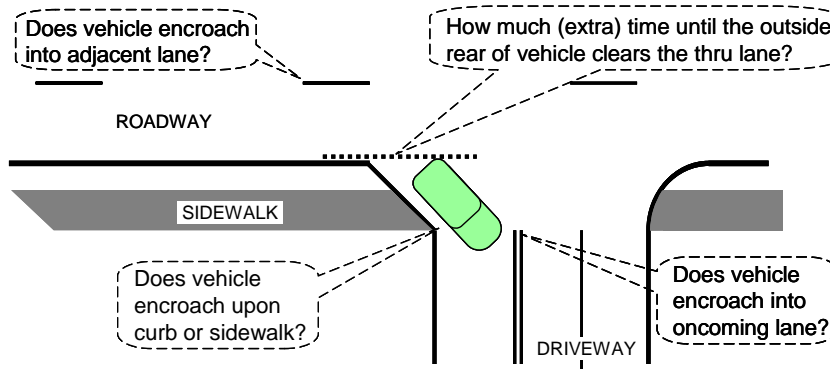
The main growth in driveways occurred after World War II when each suburban home, shopping center, drive-in theatre, etc. required driveways. The AASHTO and ITE design standards focused on "typical" driveway designs to residential and commercial activities. However, access connections to large developments such as regional shopping centers, business parks, and major activity centers changed the scale of driveway design. Multi-lane access points with center islands, large intersection radii, and long storage areas

became common. “Directional designs” that separated conflicting left-turn entering and exiting movements were sometimes installed. Examples include Shoppers World in Framingham, Massachusetts and Green Acres along Sunrise Highway in Valley Stream, New York (in the 1940s and 1950s, respectively)

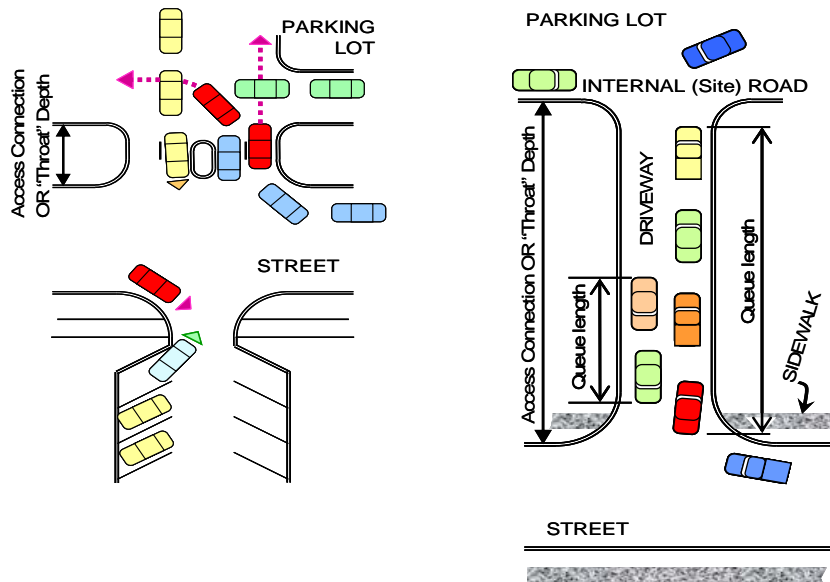
During the 1980s the concept of “access management” emerged as a means of balancing highway mobility with land access. Access classification systems identified the allowable access and the access (driveway) spacing for each highway type. Underlying goals were to maintain signal progression and improve safety. Since about 2000, greater emphasis has been placed on driveway designs that accommodate the mobility impaired.

### ISSUES AND ELEMENTS

As a result of the evolving developments, driveway design is more complex today. Access to public roads needs to be consistent with access management standards, yet still provide sufficient access to businesses and other activities. Driveway “plan view” geometry should provide sufficient turning radii and driveway width to permit left-turn entry and exit, without requiring excessive pedestrian crossing distances. Curbed driveway radii are desirable to define driveway access, but should be detectable and readily traversable by the mobility impaired. Driveway grades across sidewalks (i.e. “cross slopes”) should not exceed 2 percent. Examples of current issues relating to driveway geometry and design are shown in Figures 1 and 2.



**Figure 1 Driveway plan-geometry design considerations**



**Figure 2 Driveway throat-design issues**

Addressing these issues should reflect the capabilities of the users (e.g. drivers and pedestrians), the roadway facility, and the surrounding environment -- factors that are mainly outside the control of the driveway designer. The key geometric elements that can be addressed by the designer include (5):

1. Spacing between driveways
2. Auxiliary right-turn lanes
3. Visual and tactile clues to identify the sidewalks path and location
4. Driveway width (as perceived by pedestrians and bicyclists)
5. Driveway entry geometry (related to vehicles)
6. Driveway throat (storage) design
7. Driveway border treatment
8. Channelization
9. Sidewalk cross slope
10. Driveway grade and vertical alignment
11. Roadway/driveway interface treatment
12. Elements related to driveway visibility
13. Drainage
14. Cost and constructability

## STATE OF THE PRACTICE

The “state of the practice” was established from a survey of highway agencies, contacts with stakeholder groups, and a comprehensive literature review. Key findings follow.

### Agency Survey

Sixteen state transportation agencies spread across the United States and one local agency responded to a comprehensive survey. Most states reported that their standards (or practices) may differ according to development density, land use type, or roadway characteristics. Most had an access management code or policy; used triangular islands to provide pedestrian refuge and restrict left turns; and had established relationships among driveway radius, flare, taper, dimensions, and width. A preference was reported for curved entry-edge transitions rather than flared or tapered treatments. A plurality required paving driveways to the right-of way line. No agency allowed a direct connection with an unpaved driveway. Reported problematic issues included those related to driveway grades and to entry-edge transitions.

Agencies were asked to list their design criteria. Table 1 gives the ranges in the values reported by the agencies.

### Literature Review

A comprehensive literature review was made of more than 90 documents related to motorized vehicles and driveways, although a few documents, mainly since 2000, addressed pedestrian movements. Most documents involved research investigations, while the remainder dealt with recommended guidelines or practices.

- Non-motorized research included bicycles and drainage, pedestrian characteristics, and pedestrian gap acceptance.
- Motorized research included access management, auxiliary lanes, driveway entry and turning geometry, vertical geometry and safety.
- Guidelines addressed both driveway geometry and ADA requirements.

Neither the literature review nor agency surveys found any guidelines requiring on-site vehicle turn-around capabilities or pedestrian access from roadway sidewalks to developments.

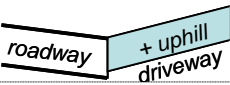
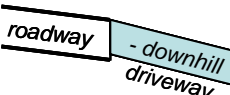
#### *Highlights from the Literature Review of Research Related to Non-Motorized Users*

AASHTO’s 2004 guide for pedestrian facilities (6) recommended a minimum width of 4.67 feet to accommodate two side-by-side pedestrians and 5.0 feet to allow two wheel chairs to pass side by side.

Fitzpatrick, et al (7) recommended a walking speed of 3.5 feet/second for the general population and 3.0 feet /second where older pedestrians were a concern. Average walking speeds for disabled pedestrians generally range from 2.0 to 3.5 feet/second, depending upon the type of disability.

The Access Board’s publication related to accessible public rights-of-way found that cross slopes that exceed 1:45 (about 2 percent) significantly impede forward progress on an uphill slope and compromise control and balance in downhill travels and on turns (4,8). This led to the maximum 2 percent cross slope requirement.

**TABLE 1 Reported ranges in driveway dimensions**

↓ 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° is right-angle)	60	68	90	60	69	75	60	70	90
For 1-way drive, Minimum Angle with the roadway allowed (90° 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	

Commercial and residential criteria are given for 3 agencies

### *Driveway Spacing (Access Management)*

Many studies have analyzed the effects of driveway spacing on safety during the past 50 years. The TRB Access Management Manual (3) presents a broad range of topics related to access management. An Interim Report for NCHRP Project 3-52 (9) analyzed some 20 studies. While the specific relationships varied, the studies consistently found that an increase in the number of access points translates into higher accident rates.

Studies in Indiana (10, 11) in the 1970s, for example, found that driveway and roadway volumes are the most significant factors in estimating the number of driveway accidents per year. Driveway accidents per mile decrease when the number of commercial driveways per mile and the arterial highway average daily traffic (ADT) are reduced.

NCHRP Report 420 (9) identified how accident rates per vehicle mile increase with increasing access density and traffic signal density. The analysis of more than 35,000 accidents found that roadways with medians had the lowest rates at all access densities. NCHRP Research Results Digest 247 (12) compared Minnesota and NCHRP data. In both cases, the accident rates increased by the square root of the product of the arterial volume and the conflicting driveway volume.

### *Auxiliary Lanes/Impacts of Driveways on Arterial Street Traffic*

A set of curves from Kansas State University gives one example of procedures and warrants for determining when right-turn deceleration lanes should be provided (13). Tarawneh et al (14) found that auxiliary lane length and right-turn volumes downstream of the driveway contributed to the use of auxiliary lanes.

McCoy and Heimann (15) found that driveways increased headways by 1 to 2 seconds with the greatest effect caused by driveways that are close to the downstream intersections. Zeiden and McCoy (16) found that vehicles in a right-turn lane could restrict the lines-of-sight of motorists exiting the driveway.

NCHRP Report 420 (9) showed how the right-turning vehicles delay through traffic in the curb lane, with the percent of vehicles delayed increasing as right-turn volumes increase. The report also has curves for estimating the probability of through vehicles being impacted by a driveway. The information can be used to establish the need for a right-turn lane.

### *Driveway Entry Geometry*

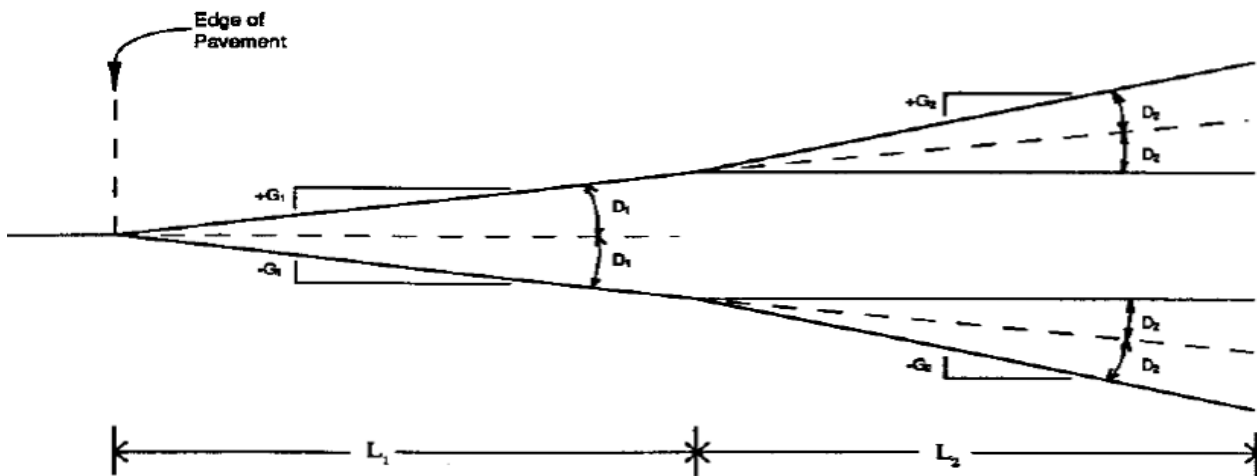
The elements of driveway entry width (throat width), entry geometry (curved radius or straight taper), and entry shape dimensions must be considered together. Stover et al (17) analyzed time-lapse photography of actual traffic streams. For typical major urban roadway volumes and speeds (45 mph) a driveway entry speed of 10 to 15 mph was considered desirable. Stover and Richards (18) further examined the effects of driveway width and radius on entry speeds. Larger entry radii and wider driveways result in higher speeds. Stover and Koepke (19) show how increasing the driveway "offset" from the curb lane allows a shorter driveway radius. Box (20) gives simplified examples that show a tight turning radius requiring the swept path of a vehicle to encroach on the opposing lanes of a 30 foot driveway, and a larger radius that enables right-turning vehicles to stay within the proper entry lane.

*Vertical Alignment*

Williams, Fambro, and Stover (21) indicated the need to avoid steep grades and suggested vertical alignment changes. Their suggested driveway design chart, shown in Figure 3, specifies maximum grades, maximum changes in grade, and minimum length of street-side grade.

Eck and Kang (22, 23) prepared design recommendations for low-clearance vehicles that experience “hang-ups” on vertical curves. They interviewed truck drivers, reviewed manufacturers’ data, and made direct measurements to obtain wheel base overhang and ground clearance dimensions on samples profiles with their previously-developed HANGUP software. By analyzing these plots and using engineering judgment, they developed design-vehicle dimensions. One example of their design recommendations (23) found that the minimum crest vertical length in feet is 4 times the algebraic difference in grades. A 1-percent difference in grades requires a 4-foot curve, a 10-percent difference a 39-foot curve.

An Oregon State University study (24) analyzed driveway speeds where grades ranged from 2.0 to 9.5 percent. Average speeds ranged from about 14 mph for a grade break of 6 percent to about 3 mph for an approximate 17-percent grade break.



TTI Rept. 990-2, p. 19

	$G_1$	$G_2$	$D_1$ 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.

**FIGURE 3 Recommended Vertical Geometry Limits in TTI Report**

*Driveway Crashes*

The literature review identified the safety effects of driveways on pedestrian and motor vehicles. A 1996 article by Stutts (25) analyzed the source of some 5093 pedestrian crashes using NHTSA data. Overall, 9 percent occurred in parking lots and 3 percent in driveways. However, half of the 351 backing vehicle-pedestrian crashes took place in parking

lots, and 13 percent in driveways or alleys. Similarly, 47 percent of the reported 346 “not in road” pedestrian crashes took place in parking lots and 15 percent in driveways.

Several studies have analyzed vehicle collisions at driveways. Azzeh et al (26) reported that driveways account for about 5 percent of the urban accidents and 7 percent of the rural accidents. The National Safety Council (NSC) cited similar figures. Two other studies suggested that driveway maneuvers accounted for 11 percent of the urban crashes and 13 percent of the rural crashes, respectively.

Box (20, 27, 28) conducted extensive studies of both aggregate and individual driveway crashes. The studies during the 1960s found that entering left turns were the greatest source of crashes. Entering left turns accounted for 43 percent of the crashes, entering right turns 15 percent, exiting left turns 27 percent, and exiting right turns 15 percent. A Texas review of driveway-related accidents between 1975 and 1977 (29) found that about two-thirds of the driveway-related crashes involved exiting movements.

Box’s 2-year study of driveway accidents in Skokie, Illinois along 39.7 miles of routes found that left turns were involved in 60 percent of all and 75 percent of injury accidents. This study analyzed the relationships among land uses, traffic volumes, and accidents in which driveways were an influencing factor. He found that accidents per commercial driveway increased with increasing traffic on surrounding roads, and that uncontrolled access openings had four times the accident frequency of shorter openings. He also found that the greater number of driveways per service station, the greater number of accidents (27). Typical driveway annual accident rates were:

- Driveway along 39.7 miles of major routes 0.13 crashes per year
- Driveways on routes with barrier medians 0.02 crashes per year
- Driveways on routes without medians 0.17 crashes per year

The numbers of crashes per year were:

- Service stations 0.15
- Other commercial and industrial uses 0.27
- Alleys 0.05
- Residential driveways 0.02

### **Design Guidelines**

A large number of documents were reviewed that provide “guidelines” for driveway spacing and design. The guidelines span close to half a century and show how their scope and depth have increased. Topics commonly covered (and commonly found) include corner clearance, spacing, left turn controls and design, intersection channelization, driveway radius (or flare) treatments and width, and vertical alignment. Guidance is more limited about the number of driveways per property (usually keyed to frontage), throat length, and building setback.

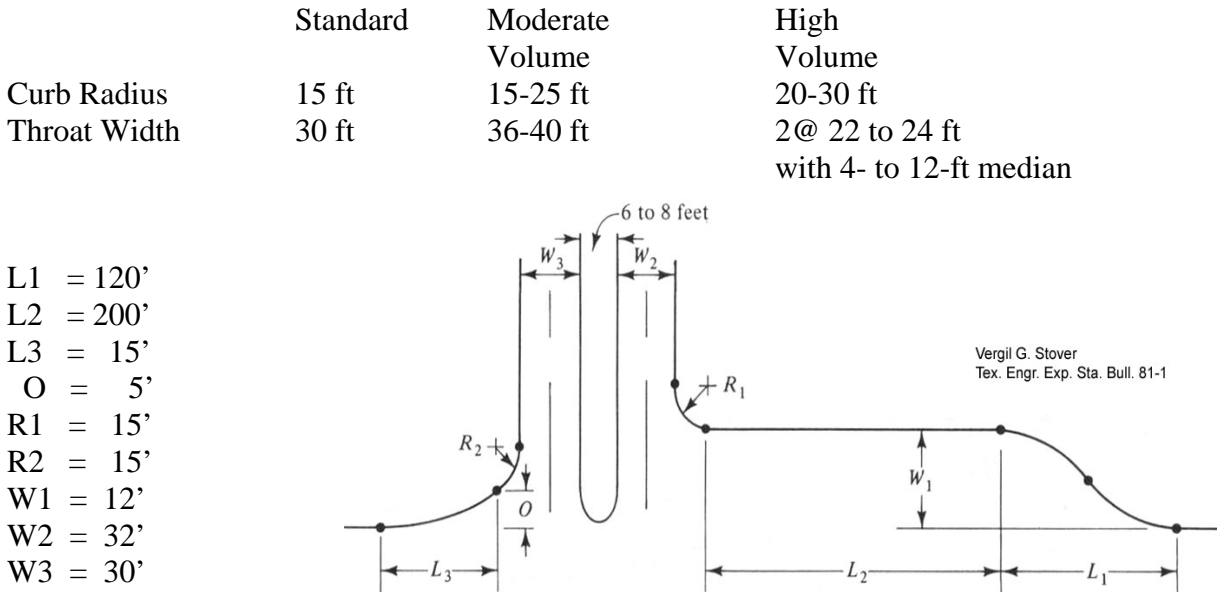
#### *Overview*

Some of the more comprehensive documents include the AASHTO informational guide (1), the ITE guidelines (2), Stover and Koepke’s Transportation and Land Development (30), the TRB Access Management Manual (3), and the Florida Driveway Handbook (31). The newer guidance incorporates access management provisions that include longer corner clearances and driveway spacing, left-turn provisions, street-like multi-lane driveways, and more on-site storage for queuing vehicles. It also limits sidewalk cross slope to 2 percent. The

earlier documents indicate shorter spacings that are, perhaps, more typical of urban environments. Most guidelines address both plan-view geometry and driveway gradients.

The AASHTO Guide (1) sets forth general principles and control dimensions for driveways. Illustrative sketches and example provide definitions, driveway controls, and typical driveway plans for various land uses, including residential, commercial, service stations and drive-in theatres. Many of the dimensions are “tight” by current standards.

Stover (18) developed guidance for auxiliary right-turn lanes, curb radii, and widths for divided driveways as shown in Figure 4. Box (32, 33) suggested the following dimensions for medium and high-volume driveways.



**FIGURE 4 Recommended driveway design with auxiliary right-turn lane**

The ITE guidelines (2) identified 23 design considerations and addressed design details such as radius, width, angle, spacing, and gradient. They recommended a minimum width of 10 feet for the typical residential driveway.

The TRB Access Management Manual (3) incorporates ADA requirements for a maximum 2 percent cross slope across sidewalks. It gives a range of designs and longer driveway spacing and corner clearance requirements than earlier documents.

*Width, Radius, and Flare*

These elements generally are addressed by most guidelines. As shown in Figure 5, the NCHRP Intersection Guide (36) suggested two different width ranges for commercial driveways (22 to 30 feet, 30 to 36 feet) depending upon whether designed for passenger cars or truck traffic and compound radii for driveway entry curves. Driveways in high-pedestrian areas and commercial driveway should be oriented at an angle of at least 70 degrees from the roadway.

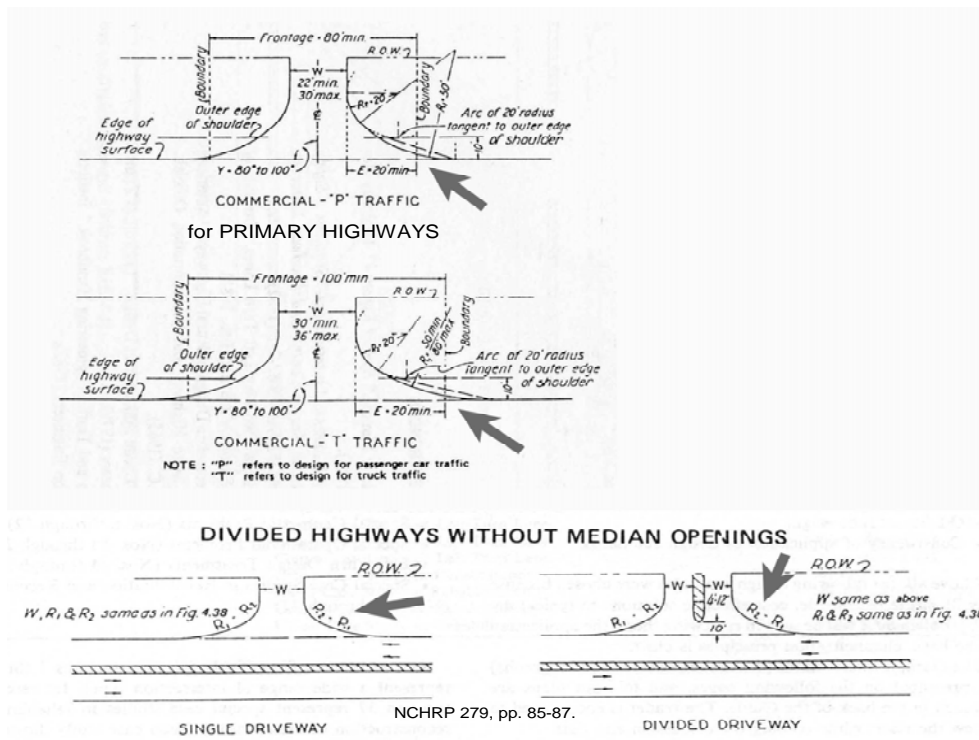


FIGURE 5 Driveway entry treatments

Examples of good and bad driveway design from the ITE guidelines are shown in Figure 6. Radii and driveway width should be sufficient to preclude drivers from encroaching upon the other direction. Koepke and Levinson (35) suggested intersection channelization and prohibition of left-turn exit movements to reduce conflicts at heavily-used commercial driveways.

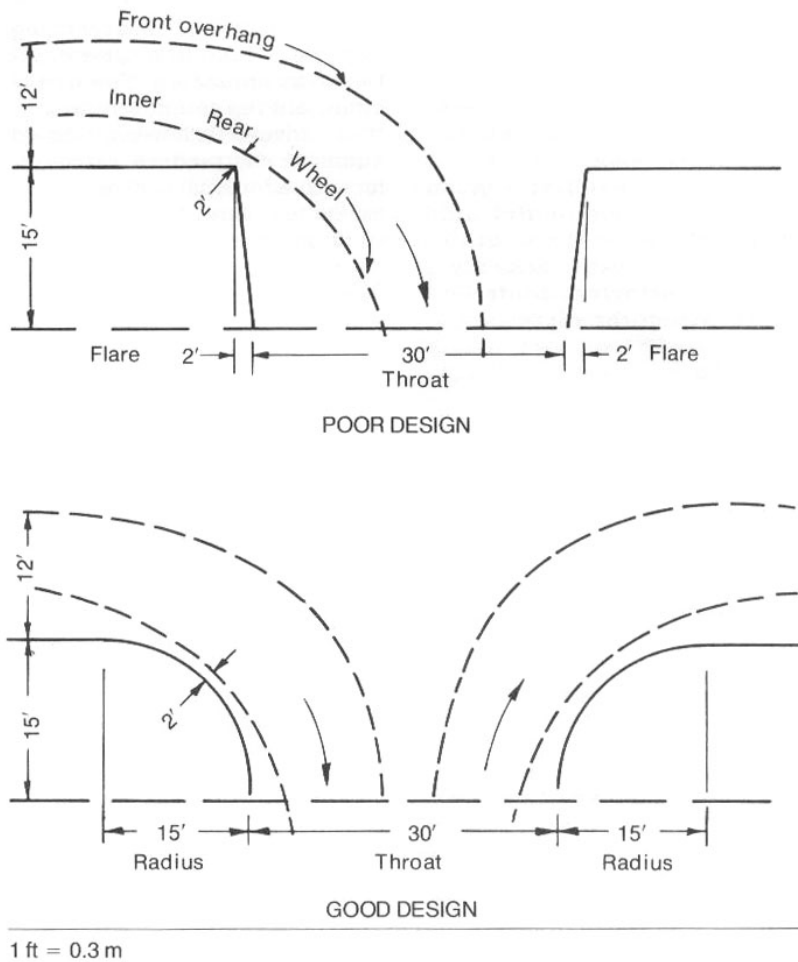


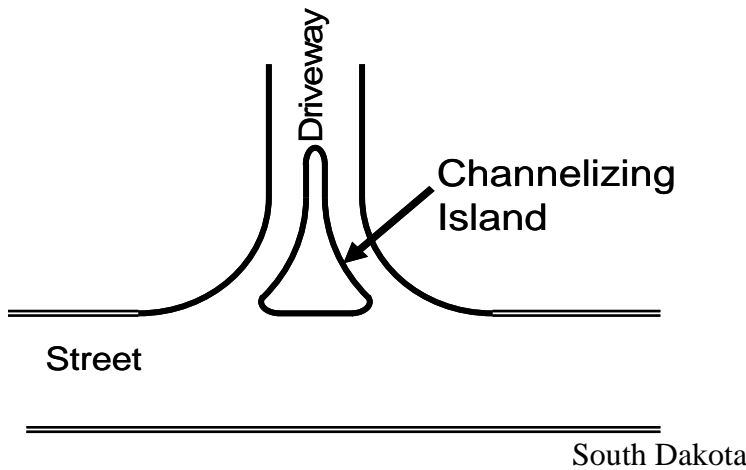
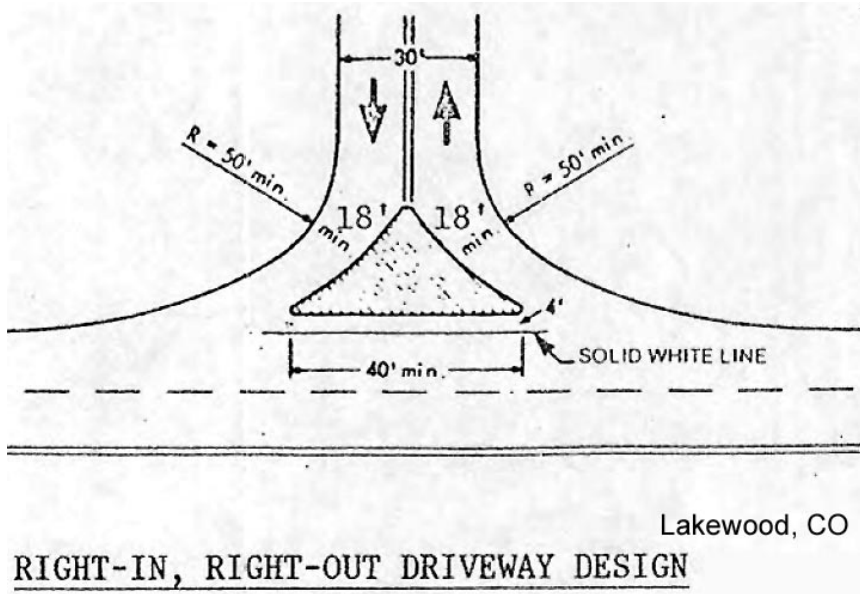
Figure 4. Swept path of passenger car turns to and from 12-foot curb lane for 2-way commercial or industrial driveways. Guidelines for Driveway Location and Design ITE, 1987, p. 9

### FIGURE 6 Driveway radius, width, and vehicle turning path

#### Triangular Islands

Some designers place triangular islands (sometimes known as “pork chops”) in driveways where they connect with the public road to allow only right-in and right-out driveway movements. Triangular islands, especially smaller ones, are not effective, since some drivers will drive around or over them to make a desired left turn into or out of the driveway. Others drivers may use the right-turn exit lane, driving the wrong way, to make a

left turn into the site,. A triangular island may be more effective if a larger turn radius is used. Some agencies install pylons along the roadway centerline to discourage wrong-way entry and egress. Figure 7 provides examples of triangular islands intended to deter left-turn movements.



**FIGURE 7 Driveway channelizing island treatment**

*Driveway Storage*

Several documents provide guidelines for driveways storage lengths based upon on a number of factors, including type of arterial highway and traffic controls, type and intensity of activities served, and parking spaces per exit lane. Box (33) suggested a connection depth that is equal to the number of vehicles turning left during the peak hour.

Standards from Lakewood, Colorado (36) identify storage distances for driveways intersecting local, collector, and arterial roadways. In each case, distances are keyed to the

type and size of activity. They range from 20 feet (low-rise apartments) to 1300 feet (large shopping centers interesting arterials). Lakewood's 1985 standards (37) identify storage distance for the main driveways based upon the number of parking spaces served (e.g. 1 percent for hospitals and 15 percent for drive-in theatres).

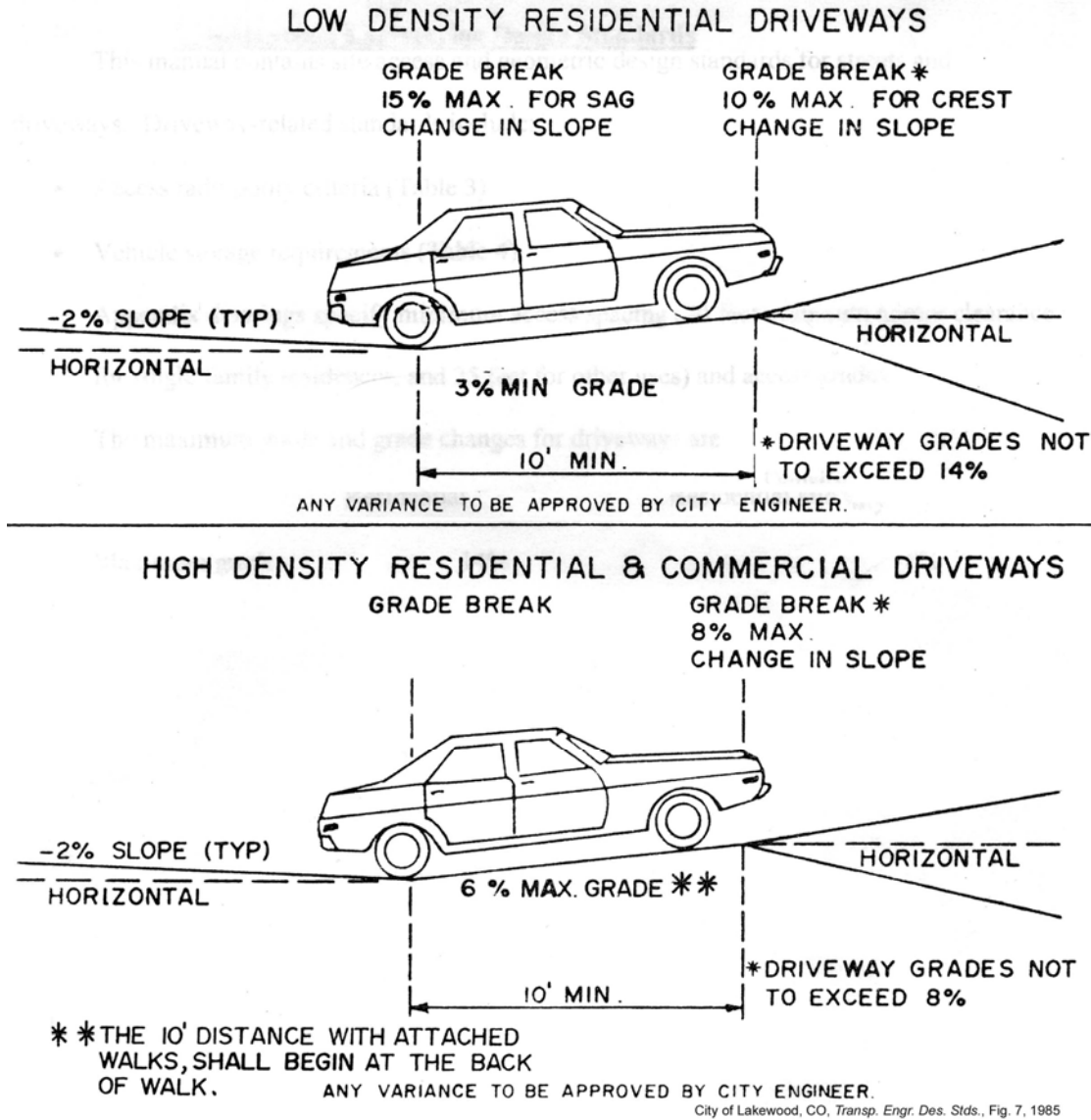
Koepke and Levinson (35) indicated that storage length should (1) be sufficient to enable vehicles to enter signalized intersections at minimum headways, (2) accommodate overlapping vehicle movements, and (3) prevent spill back. They suggested storage lengths based upon the effective red time per signal cycle and the vehicles per lane per hour. They also gave alternative guidelines based on the number of parking spaces per exit lane for major uses.

The TRB Access Management Manual (3) keyed storage requirements to the type of intersection control and the number of egress lanes. It suggested the following guidelines:

- Stop Control
  - Single lane exit > 50 feet
  - 2-lane exit > 50 feet
- Traffic Signal Control
  - 2 egress lanes -- 75 feet
  - 3 egress lanes -- 200 feet
  - 4 egress lanes -- 300 feet

#### *Vertical Alignment*

Driveway grade and profile requirements are contained in several of the guidelines reviewed. An example from Lakewood Colorado is shown in Figure 8.



**FIGURE 8 Sample vertical profile regulations**

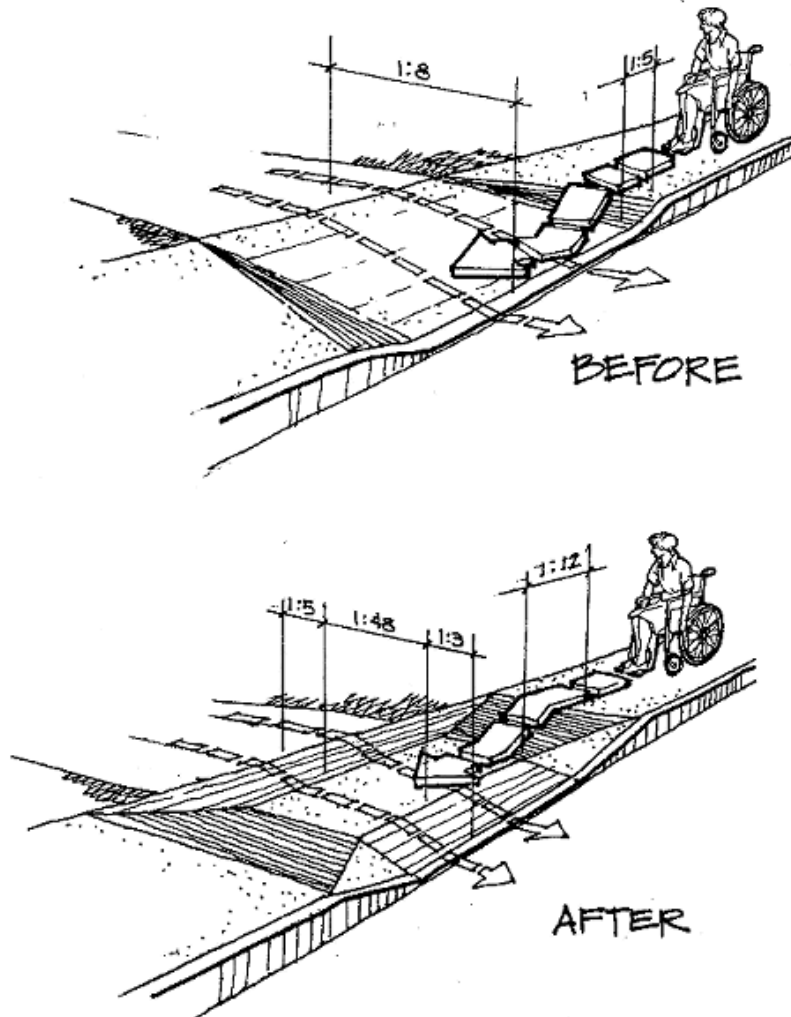
*Pedestrian and ADA Guidelines*

The US Access Board’s guidelines (4) were based on earlier recommendations of the 2001 Public Rights-of-Way Access Advisory Committee report, Building a True Community (8). The guidelines apply to all newly constructed or altered pedestrian facilities in public rights-of-way. Sidewalks are required to include a continuous pedestrian access route (PAR) that meets the following specifications:

- A surface that is firm, stable and slip resistant.
- Minimum clear width of 4.0 feet (48 inches).
- Maximum cross slope of 2% (1:48)
- The slope/grade does not exceed the grade of the adjacent roadway.
- No abrupt vertical changes of elevation in excess of ¼ inches. An elevation change between ¼” and ½” must occur over a transition slope not to exceed 1V:2H. A change in elevation over ½” must occur over a transition slope of at least 2.5 feet (30 inches).

- The gutter cross slope (or the counter slope at the base of a curb ramp) does not exceed 5 percent (1:20).

The draft guidelines do not include graphics illustrating sidewalk/driveway connections; however, graphics are available in other Access Board documents illustrating sidewalk and driveway designs. The before-and-after pair in Figure 9 demonstrates how an existing sloping driveway that lacks a level sidewalk route may be retrofitted.



**FIGURE 9 Sample before and after retrofit treatment for sidewalk-driveway crossing**

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

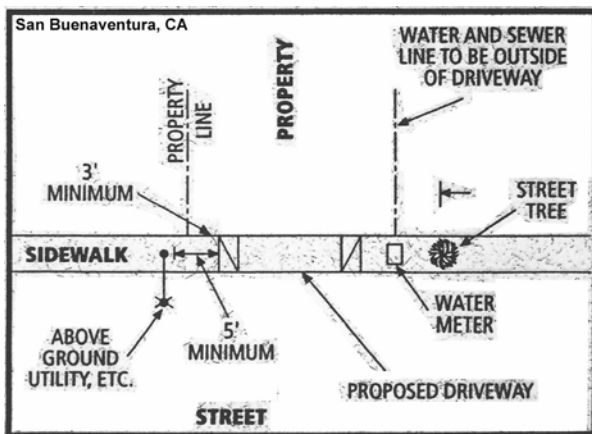
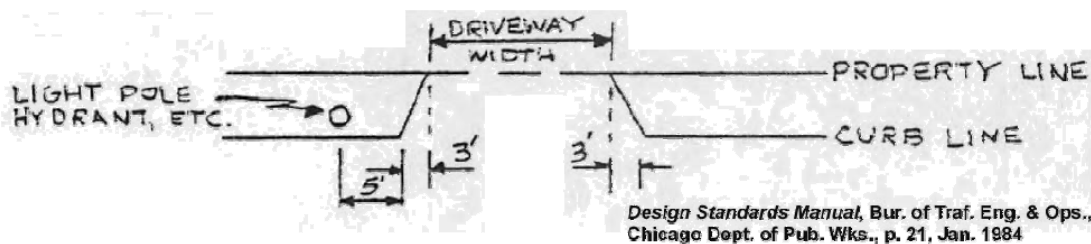
*Public Transport Stops*

A study of factors associated with the location and design of bus stops (38) included a discussion of geometric design considerations for transit buses and riders. Optimum curb heights were reported to be between 6 inches and 9 inches. 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.
- Locate a bus stop so that transit patrons board from or step onto a curb and sidewalk, not the driveway surface.

*Driveway Edge Clearance*

Several agencies specify driveway clearances from roadside utility fixtures. Examples for Chicago, Illinois (39) and San Buenaventura, California. (40) are shown in Figure 10.



**FIGURE 10 EXAMPLES of edge clearance requirements**

**IMPLICATIONS AND DIRECTIONS**

The agency survey and literature review have provided much insight regarding the various geometric designs elements. Examples include:

- (1) Removing driveway access from roadway queuing areas

- (2) Limiting the amount of open roadway frontage
- (3) Separating conflicting movements
- (4) Locating driveways away from roadside appurtenances
- (5) Providing ample storage space
- (6) Avoiding steep grades
- (7) Providing dimensions that (a) minimize delays to road traffic, (b) avoid encroaching on opposing lanes, and (c) make driveways easy for pedestrians to cross

Agencies generally provide separate guidelines for residential and commercial driveways and usually set minimum and maximum widths of driveways.

Several areas that need additional study emerged from the initial review:

- (1) Further analysis of driveway influenced crashes
- (2) Analysis of visual and tactile cues to better identify pedestrian routes across driveways
- (3) Revisiting the effects of driveway plan geometry on turning vehicles using new technology
- (4) Design of driveway triangular islands to minimize prohibited movements
- (5) Reassessing driveway vertical alignment controls to take into account newer vehicles and ADA cross slope implications

These suggestions form a context for future research investigations. The next phase of NCHRP Project 15-35 will conduct the key research and prepare guidelines for driveway geometry.

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