DRIVEWAY DESIGN ISSUES IN THE UNITED STATES

by J.L. Gattis, J.S. Gluck, J.M. Barlow, R.W. Eck, W.F. Hecker, H.S. Levinson

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ABSTRACT

This paper is based on information compiled during NCHRP Project 15-35, Geometric Design of Driveways. The research project included a literature review of over 90 documents, and survey responses from transportation agencies about their practices.

Studies have found that in urban areas, from 10% to 20% of collisions are driveway related. There are few pedestrian and bicycle collisions at driveways, but they tend to be more severe.

The research team found that a definitive basis for many aspects of driveway design were lacking. Not surprisingly, a variety of design practices was observed among agencies. Values for right-turn deceleration lane lengths, curb treatments at driveway thresholds, driveway grades, and minimum throat lengths from different sources are reported. Not only is a better understanding of the operational effects of driveway design choices needed, but also a consensus of what characteristics define good operation is needed.

The research component of the project was directed to examining the effects of vertical alignment. The researchers measured the speeds and elapsed travel times of over 1500 vehicles entering flatter, moderate, and steeper commercial driveways along suburban multilane arterial roadways. The right-turn entry radii at all sites were between 13.0 ft (4.0 m) and 19.5 ft (5.9 m). For right-turning vehicles, the 90th percentile speeds during the turn were less than 10 mph (16 km/h). For left-turning vehicles, the 90th percentile speeds did not exceed 13 mph (21 km/h).

A guide for the geometric design of driveway connections with roadways was also produced. It included simple design treatments that help disabled pedestrians cross driveways.

INTRODUCTION

Driveways are private roads that provide access (both ingress and egress) between a public way and abutting properties, and any facilities on those properties. Driveways connect and allow traffic to move between public roadways and abutting property. Driveway connections are perhaps the most common form of intersection found on public streets and highways. Traveling along a road lined with commercial or industrial land uses, it is not uncommon to find driveway connections that serve more traffic than many of the streets that intersect the roadway. Therefore, driveway connections are not the trivial design element that they may first seem to be.

In the United States, 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 (*1*). 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* (*2*) contain specific guidelines pertaining to pedestrian needs. There remains, however, an important need to better integrate vehicle and pedestrian design criteria. These considerations influenced the decision to embark upon National Cooperative Highway Research Project (NCHRP) 15-35, the Geometric Design of Driveways. This paper presents a few of the many driveway design concepts explored in the research report and the driveway design guide that were the products of this research project.

In the terminology of design engineers in the United States, the term "driveway" is often used when what is actually meant is the part of the driveway in the area near to where the driveway connects to the public highway or street. That use is employed in this paper.

WHY DRIVEWAYS DESERVE MORE CONSIDERATION

In the area where the roadway, the sidewalk and the driveway intersect, there are three distinct user groups with different and sometimes conflicting needs. 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. The flow of vehicles entering or leaving the driveway affects other motorists, as well as pedestrians and bicyclists crossing the driveway. Sometimes the flow affects traffic within the private development.

Driveways and their design have an impact not only on the flow of user traffic and the comfort of users, but also on the safety of users. During the course of the NCHRP 15-35 project, a few documents related to the safety of driveways were found. These documents provide information about the extent and types of collisions found at driveways.

Box studied the relationships among land uses, volumes, and accidents in which driveways were an influencing factor (*3*, *4*). Because 83% of all driveway accidents in Skokie, Illinois, 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. Box figured the following number of crashes per year for some facility types:

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 considered 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 on 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 remarked 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 the number of accidents (*4*).

The main focus of a series of research publications from the 1970s with titles such as "Evaluation of Factors Influencing Driveway Accidents" (*5*) was on the safety effects of driveway spacing. 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. They also found that driveway accidents accounted for 14% of the total number of accidents in four years on 100 roadway sections. Of these driveway crashes, left turn in or out movements were involved in 65% of all and in 76% of injury crashes.

A review of Texas' driveway related accidents between 1975 and 1977 (*6*) 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. 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.

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 (*7*).

Stutts et al. (*8*) 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. Considering all of the pedestrian crashes, 3% were at alleys and driveways.

An examination of six years of data from the state of Washington (*9*) produced 8,540 bicycle collision records for analysis. 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.

Rawlings and Gattis (*10*) examined over 2,000 accident reports from Springdale, Arkansas, 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. After the detailed review given to each crash report, it was determined that a number of driveway-related crashes had not been coded to indicate the driveway relationship. They found that the single highest proportions of driveway 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 two-way left-turn lane that possibly would not have occurred had a restrictive (raised or depressed) median, with or without left-turn lanes, been in place. Exhibit 1 compares their findings with those of previous studies.

DIVERGENT DESIGN PRACTICES

One of the early tasks of the NCHRP project was the listing of considerations that can affect the design of a driveway. The resulting list contained almost 100 items. As the project proceeded, the research team took note of the apparent lack of a definitive basis for the design of many of these items, and the variety of design practices observed among various local and state design agencies. To illustrate the differences, a few examples are discussed in the following parts of this section. One would not expect to find great differences among the driving populations or the vehicle types in the jurisdictions presented in the following discussion, yet the jurisdictions have adopted differing and sometimes somewhat conflicting practices.

EXHIBIT 1 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	unknown
involved pedestrians or bicyclists	4	-	-	1	1

NOTE: “-” means no value for this

Source: Rawlings and Gattis, TRB Paper 08-0710

Auxiliary Right-turn Lane Deceleration Lengths

When right-turn volumes into a driveway are heavy and/or could have a significant adverse effect on through traffic, right-turn deceleration lanes are sometimes provided to remove the slower right-turning vehicles from the through travel lanes. The benefits that accrue from having right-turn lanes include increased capacity, reduced differentials in speeds between through and turning vehicles, and reduced rear-end collision potential.

Desirably, the total length of the auxiliary lane should be the sum of the lengths needed for an entering taper, deceleration, and storage (*11*). However, common practice is to accept a moderate amount of deceleration within the through lanes and to consider the taper length as part of the deceleration length. In some higher volume and speed environments, significant deceleration in the through lanes may have adverse safety and operational effects, so deceleration in the through lanes should be minimized.

To show differences among current design practices, the design values for three agencies are presented in Exhibit 2. The braking distance component of stopping sight distance is included for comparison.

Vertical Threshold Treatments

The threshold is the edge or line where the roadway and the driveway join or touch. This line is often at the curb edge. Design concerns in this area include ease of travel for users (bicycles, motor vehicles), ease of construction, and, in cases where the roadway has a curb and gutter, confining drainage to the gutter line. Exhibit 3 shows four common driveway threshold treatments where the roadway has curbs: rolled curb, vertical lip, counterslope, and continuous.

When asked the question “What vertical treatment(s) does your agency normally use at the driveway-roadway interface?”, the survey responses from one local and 16 state transportation agencies showed the following divergent design practices (see Exhibit 4).

Maximum Allowable Grade

Three types of control for the design of the driveway profile are physical, operational, and drainage. Physical controls call for a design that maintains enough clearance so the underside of a vehicle does not scrape or drag on the roadway or driveway surface. Operational controls dictate a vertical alignment for the driveway that allows a convenient and safe entry with minimal conflicts. Drainage controls requires a profile that does not create undesirable surface-drainage patterns. The maximum driveway profile grade and the change of grade affect these controls.

The one local and 16 state transportation agencies responding to a survey have a wide range of limits on the design of driveway grades (see Exhibit 5).

EXHIBIT 2 Example deceleration lengths

Design Speed (mph)	a AASHTO Braking	b AASHTO Comfortable	c Fla (Urban)	d Fla (Rural)	e NM Stop	f NM 15mph	g Wis d2
	Deceleration Length (ft)						
30	86	170	--	--	200	175	160
35	118	--	145	--	250	230	--
40	154	275	155	--	325	300	275
45	194	340	185	--	400	370	--
50	240	410	240	290	475	450	425
55	290	485	--	350	550	525	--

-- indicates that for this speed, no value given

a. AASHTO braking is value is the braking distance (2004, p. 112)

b. AASHTO comfortable for comfortable deceleration (2004, p. 714)

c, d. Fla is the Florida Department of Transportation values, assuming 10 mph speed difference (from Std. Index 301, rev. 2005). The FDOT *Driveway Handbook* (2005, p. 63) says “Right turn lane tapers and distances are identical to left turn lanes under stop conditions.”

e, f. NM is *New Mexico State Access Management Manual*, Chp. 8, p. 92, Sep. 2001. One condition is deceleration to 0 mph, the other is to 15 mph.

g. Wis is *Wisconsin Facilities Development Manual*, 11-25-1, p. 1-3, May 2006. Distance d2 is the distance traveled while the driver maneuvers laterally and stops. The values allow a 10 mph speed difference when the turning vehicle clears the through lane.

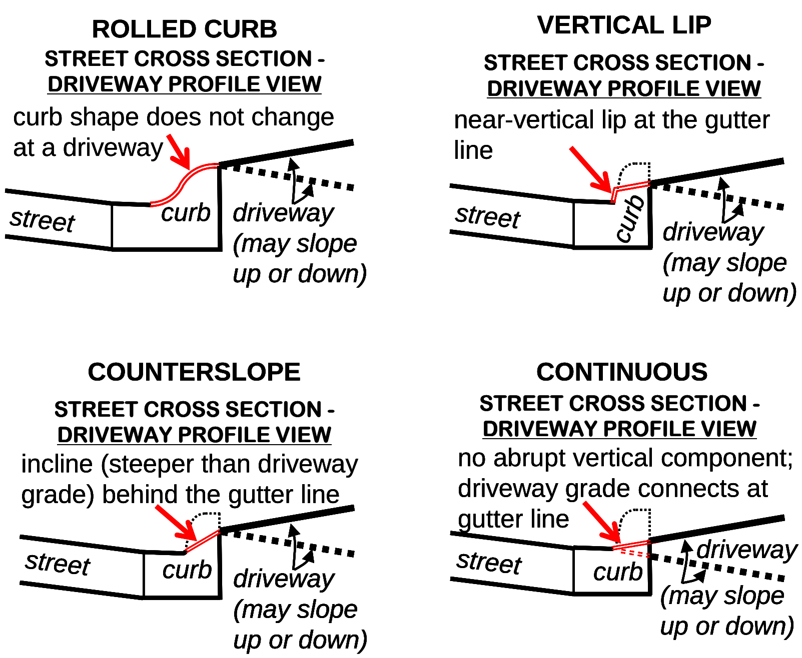
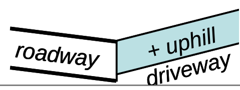
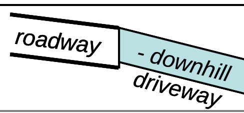


EXHIBIT 3 Common driveway threshold treatment types

EXHIBIT 4 Driveway threshold design preferences

		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

EXHIBIT 5 Driveway maximum grade design preferences

		Normally, Use This in Most Situations			Commercial			Residential	
	Smallest reported	Average	Largest reported	Smallest reported	Average	Largest reported	Smallest reported	Average	Largest reported
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

NOTE: These values reflect survey responses from 1 local and 16 state transportation agencies.

Throat Length

The driveway throat length (also known as "connection depth") is the distance from the outer edge of the traveled way of the intersecting roadway to the first point along the driveway at which there are conflicting vehicular traffic movements.

Exhibit 6 graphically displays two of the types of problems that can arise from inadequate throat lengths. When the throat length is too short to store queued vehicles, the back of the queue can extend into the through roadway and impede the flow of pedestrian and vehicular traffic. Also, a short throat can create conditions that increase opportunities for collisions between vehicles or between vehicles and pedestrians. So, throat length design can affect both the operation of traffic and the safety of the users.

The throat length should provide length to avoid spillback onto the public roadway or the internal circulation system. For multilane driveways, the throat should be sufficiently long to accommodate the crossing or weaving movements that occur between the roadways and the first-encountered crossing route within the site. So there are three different controls:

1. designing sufficient length for users to react to conflicts,
2. designing sufficient length to accommodate traffic queues, and
3. designing sufficient length to accommodate weaving.

Different sources have developed different approaches for establishing minimum throat lengths. The following narrative presents the approaches from a variety of sources.

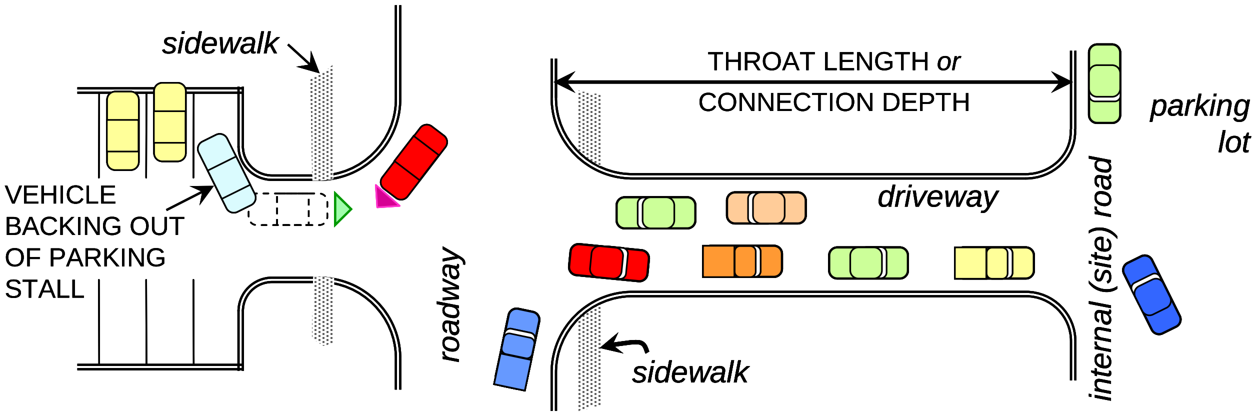


EXHIBIT 6 Driveway throat

In *Transportation and Land Development*, Stover and Koepke (*12*) state that the exit condition controls the throat length for high-volume traffic generators, while the entry condition controls the throat length for low-volume traffic generators. The exit side of a driveway should be designed to enable traffic to efficiently leave a site. The throat length and cross section are inter-related: the wider the cross section, the longer the exit throat length that is needed to accommodate the associated weaving maneuvers. Exhibit 7 presents the minimum throat length for stop-controlled and for signalized access drives, based on the number of egress or exit lanes.

EXHIBIT 7 Minimum throat length based on the type of control and number of lanes

Type of Control	Number of Exit Lanes Present 1 Exit Lane	2 Exit Lanes	3 Exit Lanes	4 Exit Lanes
STOP sign	30 to 75 ft	50 to 75 ft	--	--
Signal	--	75 ft	200 ft	300 ft

NOTE: -- indicates no value given

Source: Stover and Keopke, *Transportation and Land Development*, 2nd ed. (2002), pp. 7-24, 7-28

Another approach was presented in “Estimation of Maximum Queue Lengths at Unsignalized Intersections” from the November 2001 *ITE Journal* (*13*). It consists of different equations for different scenarios, and is too lengthy for inclusion herein.

For a comparison, Exhibit 8 presents minimum throat length criteria from a number of sources. Note that with one exception, the least required distance is 30 ft.

	NCHRP 348	TLD	Florida	Maryland	Missouri	NH	NM	Genesee NY	South Carolina
Regional shopping center	150’		250’	250’	--		250’	200’-250’	
Community shopping center	--		150’	120’	--		80’	--	
Small	50’		30’	30’	20’-60’		30’	30’-50’	
Major arterial						55			
Minor arterial						40			
Signalized, 3 exit lanes		200’							250’
Signalized, 2 exit lanes		75’							150’
Unsignalized		30’-75’							30’-50’

Note: Missouri criteria are based on volume; for this table, volumes were related to those in the Florida manual.

Sources: NCHRP Report 348, Access Management Guidelines for Activity Centers (1992)
Transportation and Land Development, 2nd ed. (2002) p.7-24, 7-28
Florida Department of Transportation, *Driveway Handbook* (2005)
Maryland State Highway Administration, *State Highway Access Manual* (2004)
Missouri Department of Transportation. “Driveway Geometrics,”940.16, *Engineering Policy Guide* [accessed 2010]
New Hampshire Department of Environmental Services, *Innovative Land Use Planning Techniques* (2008)
New Mexico Department of Transportation, “Access Location and Design Stds.,” *State Access Management Manual* (2001)
Genesee Transportation Council, N.Y., “Safe and Efficient Driveway Design” [accessed 2010]
South Carolina Department of Transportation , *Access and Roadside Management Standards*, ARMS (2008)

EXHIBIT 8 Example throat length requirements

DESIGN TREATMENTS TO HELP DISABLED PEDESTRIANS

In many environments, especially in built up areas, pedestrians will be either crossing the driveway or walking parallel to the driveway. Some of these pedestrians will have a disability, and their needs must be considered when designing a driveway. In environments where pedestrian volumes are essentially nil, pedestrian considerations may have less effect on design choices. Advocates for the disabled have identified and promoted simple changes in roadway design practices that would enable disabled pedestrians to more easily negotiate the public rights-of-way.

Where existing sidewalks do cross or future sidewalks will cross driveways, the designer must consider the horizontal alignment, the vertical alignment, and the cross slope of the pedestrian path. In the United States, aspects of sidewalk design must conform to the legal requirements of the Americans with Disabilities Act (ADA). Some sidewalk locations, and some sidewalk and driveway design choices more easily conform to ADA requirements than do others. The following discussion presents a variety of concepts to assist disabled pedestrians, some of which are not included in the ADA requirements.

Provide Visual and Tactile Cues

Visual and tactile cues that clearly define what is and is not the intended sidewalk area can assist pedestrians who are blind or who have low vision as they cross a driveway. Texture and visual contrast differences are desirable, as are some differences in the slopes of surfaces abutting the pedestrian path.

Exhibit 9 shows a sidewalk crossing a driveway. The driveway has a distinct slope toward the street. The slope extending between the edge of the roadway and the edge of the sidewalk is much greater than the slope across the sidewalk. The difference between the slopes may help pedestrians who are blind distinguish between the two areas, and avoid accidentally veering into the street area as they cross the driveway. There is a color contrast between the sidewalk and the driveway throat area. Also, a slight texture difference between the sidewalk and asphalt which can be detected by some pedestrians using a long cane.

EXHIBIT 9 Sidewalk with visual, tactile, and geometric cues crossing a driveway

Maintain a Pedestrian Access Route

A pedestrian access route (PAR) is a continuous and unobstructed walkway within a pedestrian circulation path that provides accessibility for disabled users. ADA requirements specify a pedestrian travel path or PAR with a cross slope that does not exceed 2%. The PAR requirement applies not only to the crossing of the driveway, but also to the sidewalk connections. The pedestrian crossing at newly constructed driveways must offer a minimum 48-inch wide route with a cross slope no greater than 2%. Where the driveway is an alteration to existing improvements within the public right-of-way, the pedestrian crossing portion must offer a cross slope no steeper than 2% to the maximum extent feasible, given existing site related constraints.

The combination of 2% maximum cross slope and the different sidewalk location options affect the vertical alignment of the driveway in different ways. Constraints at existing sites may prohibit strict compliance with the ADA maximum 2% cross slope specifications. They include severely limited right-of-way or sidewalk width in which to negotiate the vertical rise between the roadway elevation and the parking area, or steep existing grades on an adjoining, densely developed property that the driveway serves. Engineering judgment plays a key role during the design of driveway alteration projects where full accessibility is not being offered and that judgment may be challenged under ADA by experts analyzing every detail of the design and site factors that may or may not be found to justify any alleged access barriers created by the design.

Exhibit 10 shows methods of aligning sidewalks at driveway crossings, so that the sidewalk does not exceed the ADA 2% cross slope requirement. (Some of these designs could just as easily have a radius return instead of a flared return.)

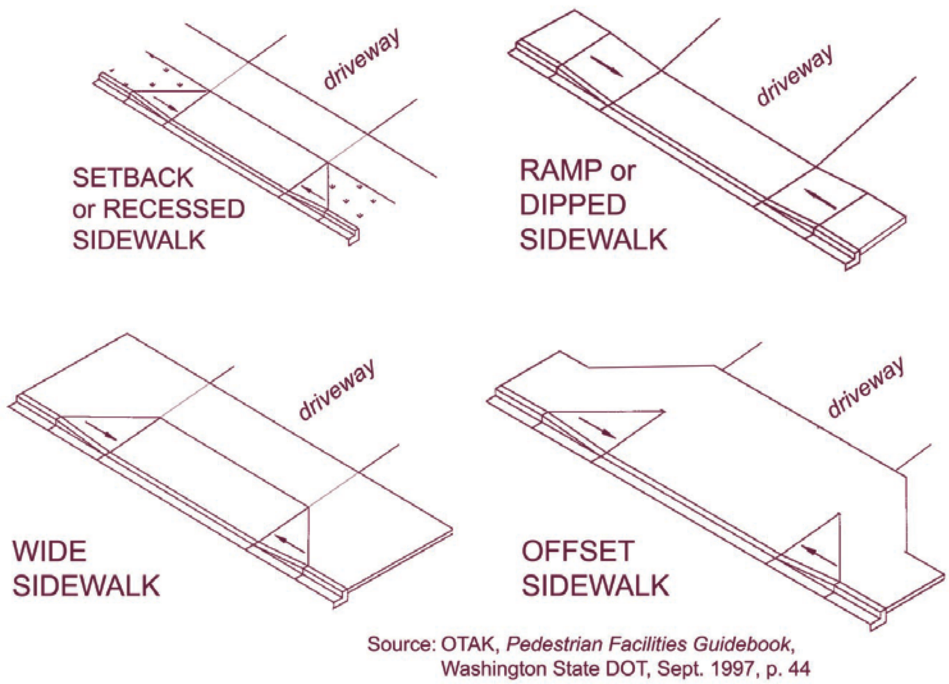


EXHIBIT 10 Treatments to maintain PAR at sidewalk-driveway crossings

Require a Minimum Driveway Length

Problems can result when vehicles entering a driveway cannot proceed far enough into the driveway, and parts of the vehicle then block the bicycle lanes or paths, or sidewalks. Items in the beds of trucks can extend over the tailgate into pedestrians' paths, creating a situation that is especially dangerous for a blind pedestrian using the sidewalk.

Unless a driveway is so short as to discourage its use for stopping or parking, then the minimum length between controlling features on each end of the driveway should be the sum of the following three components (see Exhibit 11).

1. a setback from the end toward the roadway to clear the outer edge of the traveled way, a bicycle lane or path, or a sidewalk
2. the length of the longest vehicle that typically would park there
3. a clearance buffer from a gate, garage door, or other similar end-barrier

The buffer allows a person to walk between the end of the vehicle and the end-barrier. The buffer, should also accommodate many drivers' tendencies to not pull the vehicles close to a barrier, but rather to shy away from it. The driver of a vehicle with load that slightly hangs over the rear will hopefully use the buffer to pull forward until the load clears the sidewalk.

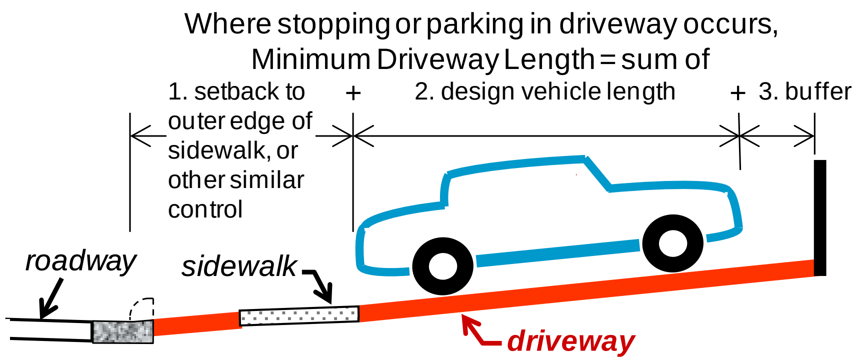


EXHIBIT 11 Minimum driveway length

VERTICAL ALIGNMENT RESEARCH

The NCHRP 15-35 project include a field data collection and analysis component focused on selected issues related to design of the vertical alignment of driveways.

The project oversight panel directed the researchers to obtain dimensions of a few vehicles to define the ground clearance characteristics. The researchers measured underclearance dimensions of a Camaro, and Corvette, a Class A motor home, and a beverage delivery tractor-trailer. Manufacturer dimensions were obtained for a pickup pulling a low trailer. From these dimensions, the grade change angles that would cause the vehicle to drag were calculated. A limitation of this approach is that it accounts for neither additional static loading on the vehicle (such as weight of the passengers or cargo), nor the vertical displacement resulting from the dynamic forces on the vehicle in motion.

The researchers also measured dimensions at 31 driveways at which vehicle scrape marks were observed on the pavement surface. From the analysis of these dimensions, it was recommended that for typical commercial and residential driveways, the maximum allowable crest breakover (i.e., change of grade) should be 10%, and the maximum sag breakover be 9%. These values were less than those arrived at from the underclearance measurements, except for that of the pickup with a low trailer.

The great majority of the effort was directed toward measuring the speeds and elapsed times of over 1500 vehicles observed turning right or left into a driveway. The studies were conducted at 12 commercial driveways on arterial multilane roadways with posted speeds of 40 and 45 mph. These were all in non-fringe suburban areas; that is, they were located in well-developed, established areas, not close to areas still in a rural state. All of the roadways had either a raised median or a two-way left-turn lane (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. Measured speeds and travel times at the Flatter, Moderate, and Steeper driveway entries were compared. Exhibit 12 displays the sensor patterns used, one for right-turning and one for left-turning vehicles.

The Flatter driveways had grades between 1.5 and 5%, and breakover angles between the roadway cross slope and the driveway grade of 3.5 to 6.5%. The Moderate driveways had grades between 6 and 9%, and breakover angles of 5 to 10.5%. The Steeper driveways had grades between 12.5 and 15.5%, and breakover angles of 13.5 to 19%.

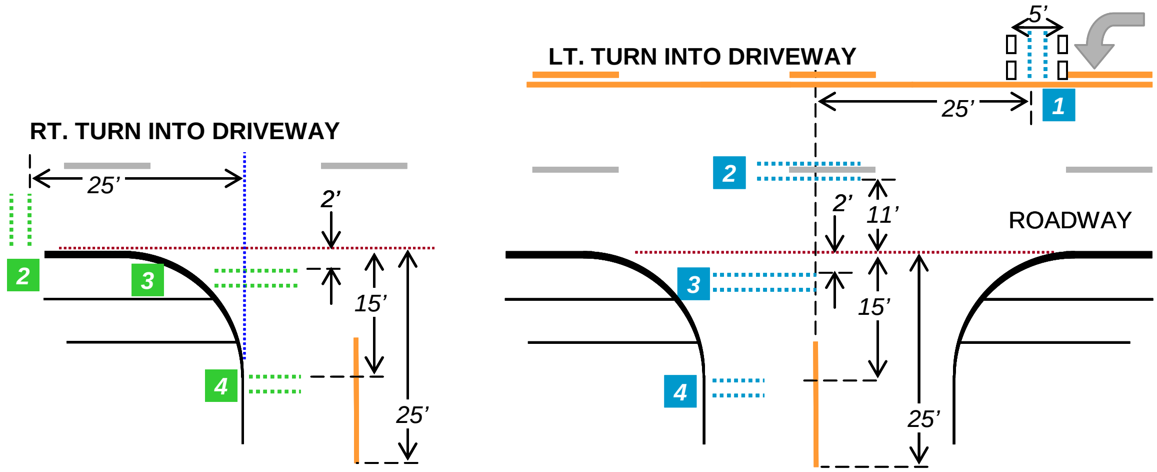


EXHIBIT 12 Sensor layout diagrams

Very few of the observed vehicles about to enter a driveway exceeded 20 mph. After crossing the driveway threshold, 90th percentile speeds for vehicles turning left into the driveway did not exceed 13 mph, and average left-turn speeds were around 10 mph. Speeds of vehicles that had turned right into the driveways were slightly less, with 90th percentile speeds below 10 mph, and average speeds around 7 mph.

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. The vehicles turning left into driveways exhibited greater speed and elapsed time differences by grade group than did vehicles turning right into driveways.

CONCLUSION

Driveway connections to roadways are a common intersection type in the United States. Some driveways, such as those serving commercial sites, have volumes greater than those on many streets. The findings from research studies have shown that a significant proportion of roadway collisions are associated with driveways, and the left-turning movements are over-represented in driveway collision statistics. The number of pedestrian and bicycle collisions at driveways is small, but these types tend to be more severe.

As the research project upon which this paper is based proceeded, the research team found that a definitive basis for many aspects of driveway design were lacking. Not surprisingly, a variety of design practices was observed among various local and state design agencies. Not only is a better understanding of the operational effects of driveway design choices needed, but also a consensus of what characteristics define good operation is needed. A case in point is the survey question about the driveway threshold design practices.

From the analysis of speeds and elapsed times of over 1500 vehicles observed turning right or left into commercial driveways on built-up suburban multilane arterial roadways, it was found that even along roadways with 40 and 45 mph speed limits, the speeds of almost all turning vehicles were less than 20 mph. This finding sheds light on the concerns of some that the speeds of vehicles turning into driveways are excessive and unsafe, and therefore driveways should be designed with more restrictive entries. Note that all of the driveways in the study had single entry lanes approximately 13 feet wide, and a right-turn radius of 13 to 19.5 feet. In other situations, entry speeds may be greater.

While no single paper can begin to present all of the issues pertaining to the geometric design of driveways, a sample of these issues have been discussed herein. For more information and references to additional sources, refer to the NCHRP 15-35 research report (*14*) and the *Guide for the Geometric Design of Driveways* (*15*).

REFERENCES

1. AASHO. *An Informational Guide for Preparing Private Driveway Regulations for Major Highways.* American Association of State Highway Officials, Washington, D.C., October 10, 1959, copyright 1960.
2. Access Board. *Draft Guidelines for Accessible Public Rights-of-Way*. U.S. Architectural and Transportation Barriers Compliance Board, Washington, D.C., 2005.
3. Box, P.C. “Driveway Accident and Volume Studies, Part I-General Relationships.” *Public Safety Systems*, May/June 1969, pp. 18-22.
4. Box, P.C. “Driveway Accident and Volume Studies, Part II-Service Stations.” *Public Safety Systems* (July/August 1969) pp. 15-18.
5. McGuirk, W.W. and G.T. Satterly. *Evaluation of Factors Influencing Driveway Accidents*, JHRP 76-1, Purdue University, W. Lafayette, Ind., 1976.
6. Richards, S.H. Guidelines for Driveway Design and Operation, Vol 2. *Research Report 5183-2*, Texas Transportation Institute, College Station, Tex., April 1980.
7. Hunter, W.W., J.C. Stutts, W.E. Pein, and C.L. Cox. *Pedestrian and Bicycle Crash Types of the Early 1990's*, FHWA-RD-95-163, Federal Highway Administration, Washington, D.C., June 1996, pp. 131-138.
8. Stutts, J.C., W.W. Hunter, and W.E. Pein. “Pedestrian Crash Types: 1990s Update.” *Transportation Research Record 1538*, Transportation Research Board of the National Academies, Washington, D.C., 1996, pp.68-74.
9. Wessels, R.L. “Bicycle Collisions in Washington State: A Six-Year Perspective, 1988-1993.” *Transportation Research Record 1538*, Transportation Research Board of the National Academies, Washington, D.C., 1996, pp. 81-90.
10. Rawlings, J. and J.L. Gattis. “A Detailed Study of Driveway Collision Patterns in an Urban Area.” *Compendium of Papers DVD*, Paper #08-0710, 87th Annual Meeting, Transportation Research Board of the National Academies, Washington, D.C., 2008, 15 pp.
11. AASHTO. *A Policy on Geometric Design of Highways and Streets*. American Association of State Highway and Transportation Officials, Washington, D.C., 2004.
12. Stover, V. G. and F.J. Koepke. *Transportation and Land Development*, 2nd edition. Institute of Transportation Engineers, 2002, p. 7-28.
13. Gard, J.T. “Estimation of Maximum Queue Lengths at Unsignalized Intersections,” *ITE Journal*, Vol. 71, No. 11, Nov. 2001, pp. 26-34.
14. Gattis, J.L., J. S. Gluck, J. M. Barlow, R. W. Eck, W. F. Hecker, and H. S. Levinson. Geometric Design of Driveways, NCHRP 15-35, Transportation Research Board of The National Academies, Washington, D.C., in press.
15. Gattis, J.L., J. S. Gluck, J. M. Barlow, R. W. Eck, W. F. Hecker, and H. S. Levinson. *Guide for the Geometric Design of Driveways*, Transportation Research Board of The National Academies, Washington, D.C., in press.