Ramp Exit/Entrance Design—Taper Versus Parallel and Critical Dimensions

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The basic design criteria, and thereby design standards, used by governmental agencies to design exit and entrance ramp terminals have not changed in more than 30 years. However, the design details of the ramp terminals vary across the country. A survey of state departments of transportation (DOTs) indicates that there is mixed use of (*a*) only tapered lanes, (*b*) only parallel lanes, and (*c*) a combination of both tapered- and parallel-lane design. Forty-one (91 percent) of 45 state DOTs that responded to a nationwide NCHRP survey prefer a tapered design for exit ramps. Thirty-four (75 percent) of the responding states use a parallel design for entrance ramps. Most agencies use AASHTO policies as a basis for speed-change lane design and either comply with or exceed AASHTO recommendations for deceleration lane lengths. However, some state standards indicate minimum lengths of acceleration lanes that are less than the minimum lengths recommended by AASHTO. Most research indicates that operational aspects of the current design elements are acceptable for today's driving conditions. The "gore" or "wedge" of exit ramps ranks high in the location of freeway accidents, and some problems exist with respect to driver gap acceptance on entrance ramps. Both conditions have been attributed to the assumption that drivers do not know how to properly use, or just do not properly use, speed-change lanes.

For many years, in fact for decades, considerable discussion has been given to the operational aspects of either the taper- or parallel-lane design of freeway ramp terminals—the speed-change lanes. Some speed-change lane design criteria are based on data collected as far back as the 1940s and 1950s.

Although design elements vary between a tapered and a parallel ramp terminal, operational aspects are normally not that different. The taper design works on the principle of direct entry to or exit from a freeway at a flat angle. The parallel design provides an added lane for speed-change purposes. In theory, the taper design reduces the amount of driver steering control and, especially on exit ramps, fits well the direct path preferred by most drivers. However, taper design used on entrance ramps requires the driver to time-share between the tasks of accelerating, searching for an acceptable gap, and steering along the lane.

The parallel-type design requires a reverse-curve maneuver when merging or diverging but provides the driver with full view from side or rear-view mirrors to monitor following traffic. Most research indicates that either type, when properly designed, will operate satisfactory. Figure 1, adapted from *A Policy on Geometric Design of Highways and Streets* (*1*), commonly called the Green Book, illustrates taper and parallel design for both exit and entrance ramps.

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CURRENT PRACTICES

NCHRP sent survey forms to 60 design agencies to determine the state of the art of ramp terminal design (*2*). Agencies included those of all 50 states, FHWA, and several large design firms. The survey form included questions regarding the type of speed-change lanes used, ramp terminal design criteria, and operational experiences. Forty-five responses were received and reviewed. A summary of survey responses indicate that 4 agencies (9 percent) preferred the use of parallel design, 11 (24 percent) preferred a taper design, and 30 (67 percent) used both parallel and taper design. Agencies using both parallel and taper designs use a taper for exit ramps and a parallel lane for entrance ramps.

Most agencies use AASHTO policies as a basis for speed-change lane design and either comply with or exceed AASHTO recommendations for deceleration lane lengths. There is some difference in minimum acceleration lane lengths, where some state standards are less than the minimum lengths recommended by AASHTO.

THE EXIT PROCESS

The operational areas of both speed-change lanes (acceleration and deceleration) are operationally composed of thre sections. The deceleration or exit lane begins with a tape section, the section in which drivers laterally shift from th through lane to the deceleration lane. For parallel ramp design, this is the section that begins at the edge of the freewa lane and transitions to the full ramp lane width, normally 1 ft. For taper ramp design, this is the section from the freewa edge to a point along the taper that is 12 ft from the edge o the freeway pavement. For design purposes, it is assumed tha this maneuver is done in 3.5 sec and that no deceleration i conducted while in this section. Therefore, the taper sectio is not included as part of the speed-change length. The secon section is the length of lane in which drivers decelerate i gear without applying brakes, which averages an addition 3.0 sec. The third section is the length in which the driv decelerates by applying brakes until the speed is equal to t average running speed of the first ramp curve. The time ne essary to complete this maneuver depends on the radius o the first ramp curve beyond the ramp "gore" or "wedge area. For design purposes, the second and third sections a designed as one unit.

AASHTO and all but four states surveyed during the NCHR study prefer the taper design for exit ramps. In additio research by Davis (*3*) indicates that nearly all exiting vehicl

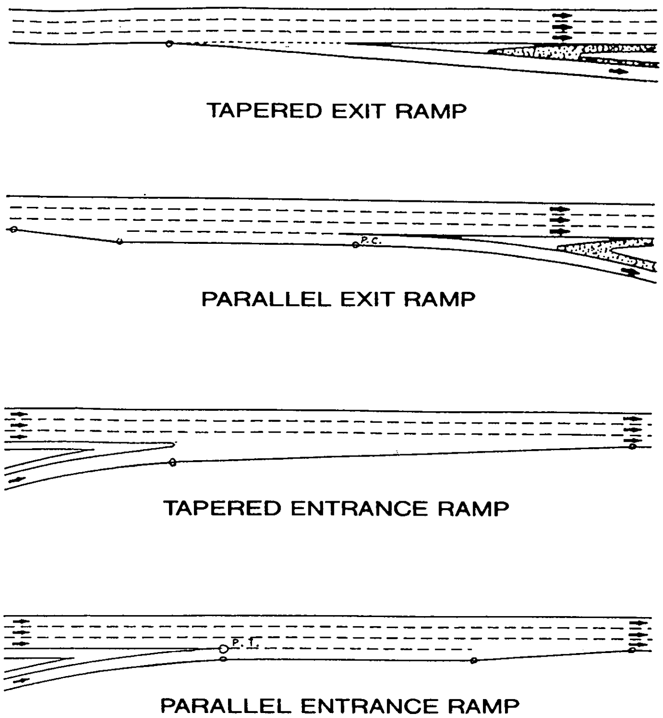


FIGURE 1 Typical ramp exit/entrance design (*1*).

(95 percent) tend to drive directly for the ramp proper even if the ramp terminal is designed as a parallel type. They did not use the taper and then drive parallel to the through lane. In fact, it was found that most vehicles began entering the deceleration lane in the taper section but did not completely clear the through lane until they were 50 to 200 ft from the ramp nose. Davis concluded that a tapered exit ramp would fit vehicle paths better than the parallel type and that AASHTO-recommended lengths for deceleration seem to be sufficient for the necessary speed reduction.

THE ENTRANCE PROCESS

The entry process differs from the exit process in that in addition to making a lane switch, the driver must make a gap search and acceptance decision. Traversing the entrance or acceleration lane involves maneuvering decisions from the initial approach to the speed-change lane, to acceleration, and then to the maneuver to enter the freeway though lane.

The first of the three operational sections of the entrance lane begins when the ramp driver transitions from the curvature of the ramp proper to the flatter geometry of the speed-change lane. It is recommended that the last curve of the ramp proper be designed for at least the average running speed of the highway. The second section allows for acceleration to the freeway running speed and the evaluation of gaps in freeway traffic. This section is the key component of the entrance lane. The third section is the taper area. The taper length for parallel-type ramps should be a minimum of 300 ft and for taper-type ramps should begin when the ramp width equals 12 ft. As with the exit ramp, the taper area is not included in the speed-change length. The slope, or taper ratio, of a taper-type ramp, of the ramp edge of pavement with respect to the freeway edge of pavement should remain the same from the ramp curve to the end of the entrance lane. A taper design with a 50:1 taper ratio is recommended as a desirable minimum.

Research by Polus and Livneh (*4*) indicates that drivers on parallel lines tend to merge before the middle of the acceleration lane. Drivers on tapered lanes tend to merge between the $\frac{1}{2}$ and $\frac{3}{4}$ section of the acceleration lane length. The research also indicates that acceleration rates are moderate to low compared with the capability of modern vehicles.

In general, states vary in the use of either taper or parallel ramp design. However, the Green Book (*1*) indicates "a decided trend toward the use of the taper type, both for deceleration and acceleration."

Most researchers viewed the operational problems associated with speed-change lanes as (*a*) drivers misunderstand the proper use of the lane, (*b*) the speed differential between ramp traffic and main line traffic is higher than the 5-mph speed difference used by AASHTO, and (*c*) drivers accept shorter taps in freeway traffic than has been expected.

Lundy (*5*) conducted a study of the effect of ramp type and geometry on accidents that indicates that accident rates on entrance ramps were consistently lower than exit ramp accident rates.

DESIGN CRITERIA

Factors considered in the design of speed-change lanes include the design speed of the highway, the design speed of the ramp curve adjacent to the speed-change lane, roadway gradients, and traffic volumes.

Exit Ramps

Figure 2 shows some of the design elements associated with exit ramps. One of the most critical elements is the distance provided to decelerate from at least the average running speed of the highway to the design speed of the initial ramp curve. The design speed of the ramp curve is dependent on the radius of the ramp curve and the rate of ramp superelevation. A vehicle should be able to leave the highway lane, transition laterally to the ramp proper, and decelerate to ramp speed, all within the "speed-change" portion of the exit terminal.

Table 1 indicates current AASHTO minimum deceleration lengths for exit terminals with grades of 2 percent or less. The table is reproduced from the 1990 Green Book (*1*) and has not changed since the 1965 AASHTO Blue Book (*6*). Lengths are based on a 3-sec time period for deceleration in gear.

As mentioned above, the taper section is not considered part of the speed-change length. AASHTO recommends that the taper section be 250 ft in length if the ramp is a parallel type and, if the design is a taper type, that the transition area be from the freeway edge of pavement to a point where the ramp pavement is 12 ft wide. Current AASHTO policy (*1*) recommends angles of divergence for taper-type ramps of between 2 and 5 degrees.

The exit "gore" is the area downstream from the point that the ramp left edge of pavement diverges from the freeway

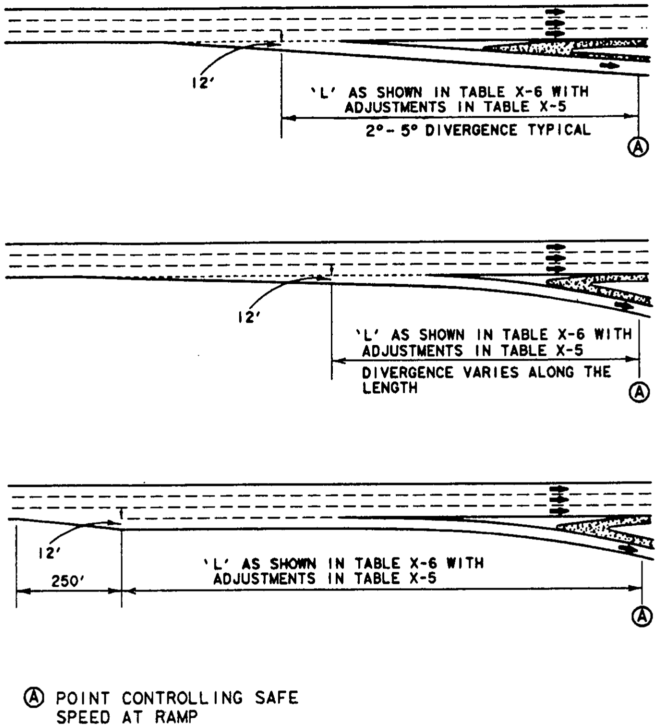


FIGURE 2 Exit ramps, single lane (*1*). *Top*, tapered design, tangent; *middle*, tapered design, curvilinear; *bottom*, parallel design.

edge of pavement to the gore nose. The gore nose is typically 20 to 30 ft wide and is the end of a paved neutral area. The entire area should be delineated with pavement markings. The entire section of the neutral area should be paved with either a combination of concrete pavement and shoulder material or with shoulder material. The unpaved area beyond the gore nose should be as level as possible. A typical gore area is shown in Figure 3.

A modification of the typical core area shown in Figure 4 is a gore that includes recovery areas. The accident rate at

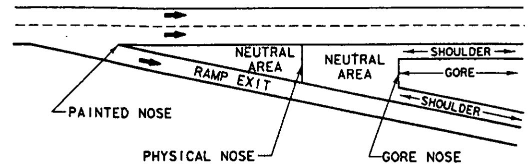


FIGURE 3 Typical gore area characteristics (*1*).

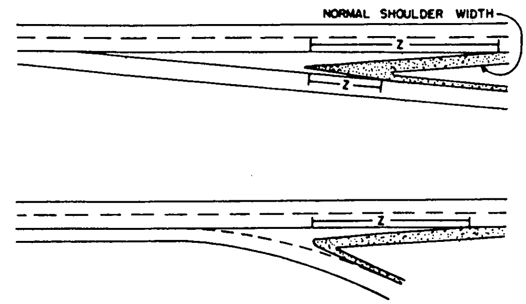


FIGURE 4 Exit gore with recovery area (*1*). *Top*, taper type; *bottom*, parallel type.

gore areas is one of the highest, and the inclusion of recovery areas will improve safety conditions. Figure 4 shows an exit gore with recovery areas along both the freeway and the ramp. It is recommended that the recovery area along the freeway be at least the width of the paved shoulder and that the recovery area adjacent to the ramp be a minimum of 3 ft wide.

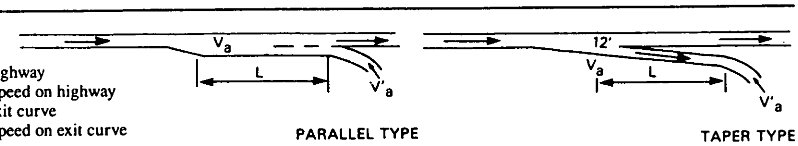
The recovery areas (Area Z in Figure 4) should taper to the respective edges of pavement. AASHTO recommends a taper ratio of one-half the design speed of the approach highway (i.e., a 70-mph freeway design speed would require a 35:1 recovery area taper, whereas a 50-mph ramp design speed would require a 25:1 recovery area taper).

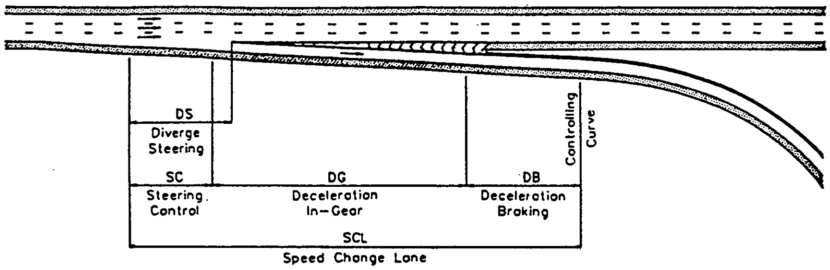
As part of NCHRP 3-35 (*2*), exit and entrance models were developed on the basis of driver behavior and traffic flow characteristics obtained from field studies and known human

TABLE 1 Minimum Deceleration Lengths for Exit Terminals with Flat Grades of 2 percent or Less

Highway Design Speed, V (mph)	Average Running Speed, V_a (mph)	Deceleration Length, L (ft) For Design Speed of Exit Curve, V′ (mph): Stop Condition	15	20	25	30	35	40	45	50
		For Average Running Speed on Exit Curve, V'_a (mph): 0	14	18	22	26	30	36	40	44
30	28	235	185	160	140	—	—	—	—	—
40	36	315	295	265	235	185	155	—	—	—
50	44	435	405	385	355	315	285	225	175	—
60	52	530	500	490	460	430	410	340	300	240
65	55	570	540	530	490	480	430	380	330	280
70	58	615	590	570	550	510	490	430	390	340

V = Design speed of highway
V_a = Average running speed on highway
V′ = Design speed of exit curve
V'_a = Average running speed on exit curve





SC - Steering Control Zone in which the driver steers and positions a vehicle from the freeway lane onto the deceleration lane.

DS - Diverge Steering Zone which is the distance upstream from the exit gore, at which a driver begins to diverge from the freeway.

DG - Deceleration in Gear Zone in which the vehicle decelerates prior to braking.

DB - Deceleration While Braking Zone in which braking occurs in order to reach a reduced speed dictated by the geometrics, terminus, or traffic conditions on the off-ramp.

FIGURE 5 The exit process (*2*).

factors. The models segmented the elements of the speed-change maneuver into additional components. Figure 5 is a diagram of the exit process. Table 2 gives the design values for the deceleration lane length (DG + DB in Figure 5) recommended in the NCHRP report.

The NCHRP report recommends deceleration lengths that are significantly higher than AASHTO.

Entrance Ramps

Figure 6 shows some of the design elements associated with entrance ramps. The most critical design is the distance provided to accelerate from the design speed of the ramp again, as with the exit ramps, dependent on the ramp radius and the rate of ramp superelevation—and the design and average running speed of the highway. A vehicle should be able to accelerate at least to the average running speed of the highway before the driver begins the merging maneuver. Table 3, reproduced from the Green Book (*1*), indicates current AASHTO minimum acceleration lengths for entrance terminals with grades of 2 percent or less. This table has also not changed from the values derived for the 1965 Blue Book (*6*).

As with deceleration lanes, the lengths are from the ramp curve to a point that is the end of the parallel lane or when the tapered ramp width decreases to 12 ft. The taper section for tapered ramps should remain unchanged with respect to the freeway pavement edge, and if the ramp type is a parallel design, a 300-ft minimum taper length should be used for parallel ramps.

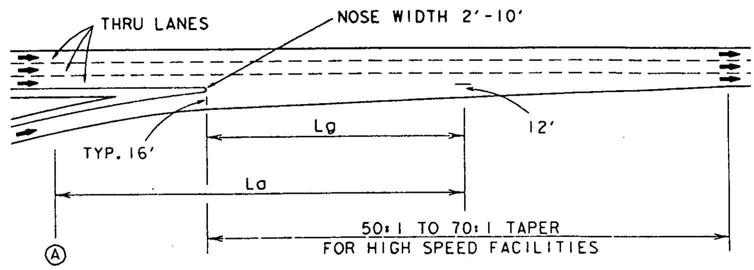
Although not a direct part of the speed-change lane, the ramp curve being used to enter the entrance ramp should be available to permit drivers to begin evaluating gaps in freeway traffic and to begin accelerating. If the ramp has a radius in the range of 800 to 1,000 ft, the motorist on the ramp or freeway will have an unobstructed view of freeway or ramp traffic, respectively.

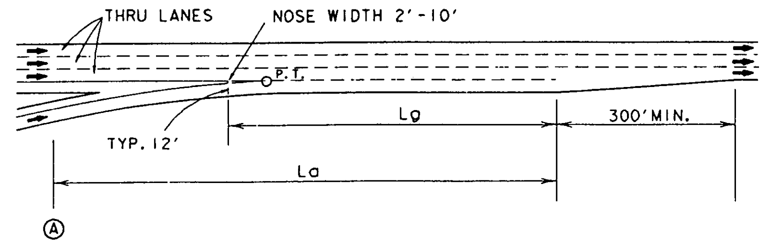
Several states use the same design lengths for all deceleration lanes and all acceleration lanes, no matter what radius or design speed is used on the ramp curve entering or leaving the speed-change lanes. This consistency of design should aid driver familiarity.

TABLE 2 Deceleration DesignValues (*2*)

	Deceleration Lane Length (ft.)		
V'_d (mph)	V'_c (mph) 15	30	50
70	1,035	825	825
60	730	730	535
50	630	630	435

V'_d = Freeway diverge speed
V'_c = Ramp controlling speed





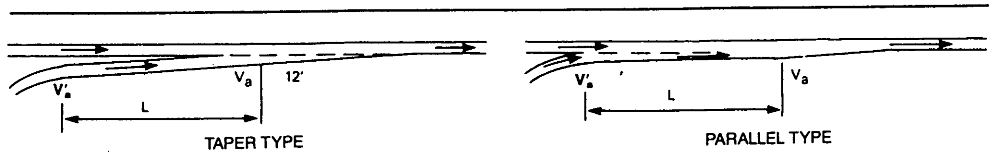
NOTES:

1. La IS THE REQUIRED ACCELERATION LENGTH AS SHOWN IN TABLE X-4 OR X-5.
2. POINT Ⓐ CONTROLS SAFE SPEED ON THE RAMP. La SHOULD NOT START BACK ON THE CURVATURE OF THE RAMP UNLESS THE RADIUS EQUALS 1000' OR MORE.
3. Lg IS REQUIRED GAP ACCEPTANCE LENGTH. Lg SHOULD BE A MINIMUM OF 300' TO 500' DEPENDING ON THE NOSE WIDTH.
4. THE VALUE OF La OR Lg, WHICHEVER PRODUCES THE GREATEST DISTANCE DOWNSTREAM FROM WHERE THE NOSE WIDTH EQUALS TWO FEET, IS SUGGESTED FOR USE IN THE DESIGN OF THE RAMP ENTRANCE.

FIGURE 6 Typical single-lane entrance ramps (*1*). *Top*, tapered design; *bottom*, parallel design.

TABLE 3 Minimum Acceleration Lengths for Entrance Terminals with Flat Grades of 2 percent or Less

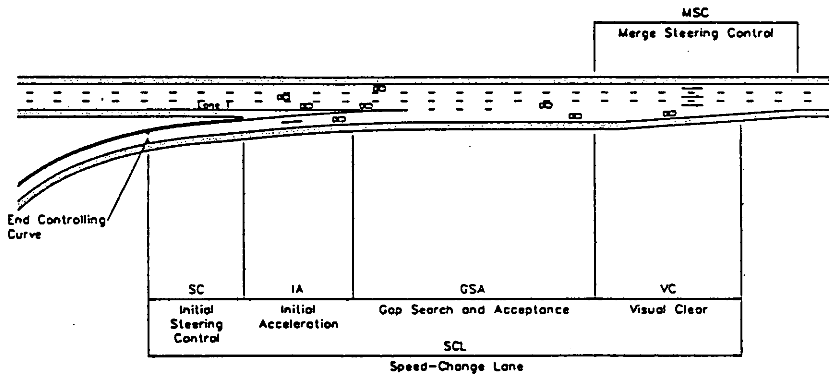
Highway		Acceleration Length, L (ft) For Entrance Curve Design Speed (mph)								
		Stop Condition	15	20	25	30	35	40	45	50
Design Speed (mph)	Speed Reached, V_a (mph)	and Initial Speed, V_a' (mph)								
		0	14	18	22	26	30	36	40	44
30	23	190	—	—	—	—	—	—	—	—
40	31	380	320	250	220	140	—	—	—	—
50	39	760	700	630	580	500	380	160	—	—
60	47	1,170	1,120	1,070	1,000	910	800	590	400	170
70	53	1,590	1,540	1,500	1,410	1,330	1,230	1,010	830	580



Note: Uniform 50:1 to 70:1 tapers are recommended where lengths of acceleration lanes exceed 1,300 feet.

The nose of the entrance ramp, or "merging end," is the point where the area between the ramp's left edge of pavement and the freeway's right edge of pavement, assuming a right-hand ramp, is paved. The nose width varies from 2 to 10 ft depending on local design standards. The ramp pavement width opposite the nose varies from 12 to 16 ft. The total offset of the ramp's right edge (18 to 22 ft) and the ramp's taper ratio will determine the total length of a taper-type acceleration lane.

The NCHRP 3-35 model also developed design values for entrance ramps. Figure 7 is a diagram of the entry process, and Table 4 gives recommended design values developed for the acceleration lane length (IA and GSA in Figure 7). This distance corresponds to "La" in Figure 6.



SC - Steering Control Zone which involves the steering and positioning of the vehicle along a path by steering from the controlling ramp curvature onto the speed-change lane.

IA - Initial Acceleration Zone in which the driver accelerates to reduce the speed differential between the ramp vehicle and the freeway vehicles to an acceptable level for completing the merge process.

GSA - Gap Search and Acceptance Zone during which the driver searches, evaluates, and accepts or rejects the available lags or gaps in the traffic stream. This zone is the key component of the entry model.

MSC - Merge Steering Control Zone during which the driver enters the freeway and positions the vehicle in Lane 1. This zone, however, is not considered a determinant of the speed-change lane length.

VC - Visual Clear Zone which provides a buffer between the driver and the end of the acceleration lane. Once a driver reaches this zone, he must take one of two actions, either merge onto the freeway in a forced maneuver, or abort the merge process and begin to decelerate at a reasonable rate.

FIGURE 7 The entry process (*2*).

TABLE 4 Acceleration Design Values (*2*)

Acceleration Lane Length (ft.)						
	v^1_o = 15 mph			V^1_o = 30 MPH		
	v^1r_1 (mph)			v^1_{r1} (mph)		
v^1_f (mph)	40	50	60	40	50	60
70	2,550	2,025	2,400	2,475	1,975	2,425
60	1,750	2,025	*	1,675	1,975	*
50	1,700	*	*	1,625	*	*

* For this design condition, use next lowest value of v_r

V'_f = Freeway speed

v'_o = Initial ramp speed

v'_{r1} = Ramp speed at beginning of GSA zone

INTERPRETATION

Although basic criteria and thereby design standards used by governmental agencies have not changed in more than 30 years, most researchers who have investigated the operational aspects of speed-change lanes have found current design elements to be acceptable for today's driving conditions.

A survey of nationwide design agencies indicates that two-thirds of the agencies use both taper- and parallel-type speed-change lanes, depending on location and freeway conditions. Nearly all agencies use deceleration lane lengths that equal or exceed AASHTO recommendations. The greatest design difference lies in acceleration lane lengths, which in some cases are less than AASHTO recommendations.

Most researchers indicate very few operational problems with deceleration lanes. However, the gore of exit ramps ranks high in the location of freeway accidents. Researchers also indicate some problems with driver gap acceptance occurring on entrance ramps. Both conditions have been attributed to the assumption that drivers do not know how to properly use, or just do not properly use, speed-change lanes.

Little literature was found dealing with the impact of traffic control devices, including signals, signing, and striping at freeway/ramp merge or diverge areas.

No research was found describing the effect of ramp metering on acceleration lane length and operation or the operation of speed-change lanes at night with or without roadway lighting. Additional research dealing with these types of ramp operation should be beneficial. Additional research would also be useful in evaluating the operational differences between urban and rural operation, right and left side ramps, and single and two-lane ramps.

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