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Effects of Taper Length on Traffic Operations in Construction Zones

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The study dealt with a proposed taper length formula that yields shorter tapers at design speeds below 96 km/h (60 mph) than does the existing formula (L = WS, when S is in mph). This paper reports on a direct comparison of traffic operations using both the standard and proposed taper lengths in the same construction zones. Speed, erratic maneuvers, traffic conflicts, and lane encroachment data were collected at four sites, day and night, for a variety of design speeds and taper lengths. The analyses of the data collected do not imply that the proposed taper lengths are more hazardous than the standard taper length. Use of the proposed length did not produce a greater number of erratic maneuvers and slow-moving vehicle conflicts than did the standard or existing taper length. There was no indication that the proposed taper lengths resulted in a greater number of passenger vehicle or truck encroachments on adjacent lanes.

The Manual on Uniform Traffic Control Devices (MUTCD) (1) specifies that the length of lane-drop tapers in construction zones should be computed as

$$L = WS \tag{1a}$$

where

L = Minimum length of lane-drop taper (ft),
W = Width of offset (ft), and
S = Speed limit or 85th percentile speed (mph),

or for the metric computation,

$$L = WS/1.62 \tag{1b}$$

In application the speed (S) can be considered as the design speed of the construction zone (not necessarily that of the highway). The design speed is the maximum safe speed through the construction zone. An alternative formula has been proposed to replace the standard formula:

$$L = WS^2/60 \tag{2a}$$

or for the metric computation,

$$L = WS^2/157.5 \tag{2b}$$

A comparison of taper length computed by use of each of these formulas is shown in the table below (1 km/h = 0.62 mph; 1 m = 3.28 ft).

Design Speed (km/h)	Taper Length (m) Using L = WS/1.62 (W = 3.7 m)	Taper Length (m) Using L = WS²/157.5 (W = 3.7 m)
96	220	220
89	201	185
80	183	152
72	165	123
65	146	98
56	128	75
50	110	55
40	91	38
32	73	24
25	55	14

At a design speed of 96 km/h (60 mph) a taper length of 220 m (720 ft) is computed using both formulas, at 72 km/h (45 mph) the taper length is 165 m (540 ft) using the standard formula and, using the proposed formula, 125 m (405 ft), only 75 percent as long as the standard taper length. At 50 km/h (30 mph) the standard taper length is 110 m (360 ft) and the proposed taper length is 55 m (180 ft), only 50 percent as long as standard; at 25 km/h (15 mph) the standard taper length is 55 m and the proposed taper length is 14 m (45 ft), 25 percent as long as the standard.

The proposed formula is theoretically appealing because the ability to stop and change direction is known to be inversely proportional to the square of the velocity. Therefore, if the standard taper length is adequate for 96 km/h (60 mph), then standard taper lengths for speeds less than 96 km/h are excessively long. Proponents of the revised formula point out the advantages of the shorter taper lengths: They require fewer traffic-control devices and, at urban sites, interfere with fewer driveways and intersections.

Opponents of the proposed formula believe that the taper lengths computed by the proposed formula are too short at low speeds [25 to 40 km/h (15 to 25 mph)] and that the short tapers are not sufficient to allow large vehicles such as trucks and buses to change lanes without encroaching on adjacent lanes and to prevent such large vehicles from turning over.

STUDY SITES

The alternative taper formulas were evaluated in four construction zones—one in Missouri and three in Florida. The design speeds of these four construction zones ranged from 25 to 72 km/h (15 to 45 mph). The characteristics of the four construction zones are described in Table 1.

Site 1 was studied in September 1976, in conjunction with earlier field work. These field studies considered the effects of funneling and reduction of lane width as

Table 1. Study site characteristics.

Site Number	Highway Type	Description of Traffic Control	Taper Initially Used	Design Speed (km/h)
1	4-lane undivided	Closure of right lane and diversion to two-lane detour roadway	Standard (MUTCD)	50
2	6-lane divided	Closure of right two lanes and crossover through median opening	Standard (MUTCD)	25
3	6-lane divided	Closure of right two lanes and crossover through median opening	Existing (shorter than proposed taper length)	50
4	6-lane divided	Closure of left two lanes	Standard (MUTCD)	72

Note: 1 km/h = 0.62 mph.

well as different taper lengths. Funneling is a technique of gradual reduction of the width of the traveled way by placing drums on each side of the open lanes on the approach to the construction zones. The table below shows the experimental design for the studies conducted at site 1. Experiments were conducted both day and night.

Experiment	Treatment	Level
US-1	Taper length	Proposed formula
	Funneling and lane width reduction	Not present
US-3	Taper length	Proposed formula
	Funneling and lane width reduction	Present
US-5	Taper length	Standard formula
	Funneling and lane width reduction	Not present
US-6	Taper length	Standard formula
	Funneling and lane width reduction	Present

Sites 2, 3, and 4 were studied in June 1977. Sites 2 and 4 involved direct comparison of the standard and proposed tapers without the consideration of other factors. Site 3 involved a unique situation. An existing 30-m (100-ft) median opening was used to cross traffic into the opposite roadway. The small median opening prevented the use of the standard taper and the existing taper was shorter than the proposed taper. At this site, the proposed taper was compared with the existing, shorter-than-proposed taper. The table below summarizes the experimental design for sites 2, 3, and 4 (1 km/h = 0.62 mph).

Site	Experiment	Design Speed (km/h)	Taper Formula
2	1	25	Proposed
2	2	25	Standard
3	1	50	Proposed
3	2	50	Existing condition
4	1	72	Proposed
4	2	72	Standard

FIELD STUDY PROCEDURE

The plans for the experiment were approved by the construction contractor and the cooperating state highway department before the studies began. Changes in the taper length were made only after the necessary approvals were obtained.

The first step in the field study was to install speed-measuring equipment. The basic mode of data collection used a series of tape switches connected to a 20-channel event recorder. Pairs of tape switches 30 to 15 m (100 to 50 ft) apart were placed in each lane at two locations in the zone. The tape switches were augmented by radar at a third location at sites 1, 3, and 4. The locations of the speed measurements included: (a) prior to the beginning of the zone, (b) on the approach to the zone, (c) in the entrance to the transition area, and (d) in the work area.

The approach area begins where the driver is first informed about the actual condition of the roadway ahead and the actions that will be required to travel through the work area. Although no physical restrictions narrow the roadway in the approach area, drivers often slow their vehicles and perform merging maneuvers as they adjust their speeds and positions based on their concepts of the safe path through the zone.

The transition area begins at the point where the normal roadway is altered laterally by devices such as cones, barricades, or barriers in order to channel traffic to the part of the roadway open through the work area.

The work area is that length of the roadway where work is being done or will be done. The work-area roadway may be completely closed to traffic or a portion of the roadway may be open through the work area. If the work area is open to traffic, traffic control should provide for the separation and protection of motorists and construction workers.

The switches were connected by wire to the event recorder. When a vehicle crossed the switch, the circuit was closed and vehicle passage was recorded on paper charts used in the event recorder. Almost 3 km (2 miles) of wire were required to connect the switches to the recorder. To reduce the quantity of wire required, speeds in one area of the zone were measured by radar. Three-meter (10-ft) tape switches placed perpendicular to the lane were used to record lane volumes, speeds, and headways. In the transition area of sites 1, 2, and 3, 0.6-m (2-ft) switches laid end to end were used to record information on the lateral placement of vehicles. Data from these switches were used to determine vehicle encroachments on the highway centerline.

The tape switches were installed by the project crew. During installation of the switches, traffic was controlled by a flagman and a sequential flashing-arrow trailer. The switches were secured to the pavement by duct tape. When the switches were in place and tested, the study began. Each experiment was conducted for day and night conditions. The daytime experiments were conducted from 12:00 n. to 5:00 p.m. Night studies were conducted between 7:00 p.m. and 12:00 m.n.

Two observers were present during each of the experiments. One of the observers made the radar speed measurements. The other observer was stationed in the transition area of the zone and recorded vehicle conflicts and erratic maneuvers. He also noted (on the event recorder by a special switch) the passage of a bus, which would assist in later data reduction. The erratic maneuver and conflict counts and the radar speed measurements were made for 15-min periods. The length of each experiment (day or night) was 2.5 to 3 h, which was sufficient to obtain at least ten 15-min periods of conflict data. This length of study period for conflicts data is equivalent to the conventional sample for intersectional conflict counts.

Five types of conflicts plus erratic maneuvers were monitored at each site, although all were not analyzed at each site because of the small numbers encountered. A slow-moving-vehicle conflict occurs when a vehicle is forced to brake or swerve to avoid a rear-end collision with a slower vehicle in the transition area. A weave conflict occurs when a vehicle changes lanes into the path of another vehicle, which causes the offended vehicle to brake or swerve. A slow-to-weave conflict occurs when a vehicle must brake or swerve to avoid another vehicle while changing lanes. A right-turn conflict occurs when a vehicle must brake or swerve to avoid collision with a vehicle that is turning right. A previous conflict occurs when a vehicle is forced to brake or swerve to avoid collision with another vehicle and in so doing causes a third vehicle to brake or swerve. An erratic maneuver occurs when a single vehicle brakes or swerves on the approach to the transition area. Unlike a conflict, an erratic maneuver does not require the presence of a second vehicle that causes the braking or swerving maneuver.

The observed sample sizes and speed measurements of vehicles are given below (the number of buses at site 1 was not noted separately):

Site	Trucks	Buses	Total	Number of Vehicle Speed Measurements
1	197	–	9120	5928
2	55	8	3076	1393
3	16	9	4751	3045
4	72	0	2772	2634

DATA REDUCTION

The field data were reduced by reading the paper charts from the 20-pen event recorder. The data determined from the charts included traffic volumes, traffic speeds, and vehicle classifications.

Traffic volumes were determined for each 15-min period by counts of the number of times the tapeswitch was actuated. Separate switch actuations for each axle make it possible to classify vehicle types as truck (three or more axles) and passenger automobile or bus (two axles). Buses were distinguished from passenger automobiles at sites 2, 3, and 4 by a manual actuation of one recorder pen for each bus that passed through the taper area.

Speed measurements from the event recorder charts were made by use of an overhead opaque projector to show the chart image on a rear-projection screen. The projected image was enlarged four times to permit accurate measurement of the distance on the chart that represents the time between closures of switches spaced at a known 30-m (100-ft) interval.

ANALYSIS AND RESULTS

Four general measures of effectiveness were considered in the taper length studies: speeds, traffic conflicts, erratic maneuvers, and centerline encroachments. The mean speeds, erratic maneuver rates, traffic conflict rates, and encroachment rates for each experiment are presented in Table 2. The statistical analyses and the evaluation of the relationship between each measure of effectiveness and taper length are summarized below. For further details of the analyses, refer to the recent report by Graham and Sharp (2).

Speeds

Site 1 involved a closure of the right lane of an urban, four-lane, undivided arterial street. Speeds at site 1 were measured at three locations: location 1 (L1) was 0.8 km (0.5 mile) upstream of the lane closure, location 2 (L2) was 310 m (1000 ft) upstream of the lane closure, and location 3 (L3) was at the center of the barrel taper. At this site the effect of taper length was studied in conjunction with the effect of the presence or absence of funneling and lane-width reduction. These effects were separated by an analysis of variance of the following factors and levels (1 km = 0.62 mile; 1 m = 3.28 ft):

Factor	Level
Taper length (T)	T1 = Proposed formula
	T2 = Standard formula
Funneling and lane width reduction (F)	F1 = Not present
	F2 = Present
Time of day (t)	t1 = Day
	t2 = Night
Location (L)	L1 = 0.8-km upstream
	L2 = 310-m upstream
	L3 = Center of taper

The results of this analysis of variance are given in Table 3. This table illustrates the format of the analysis of variance results that were obtained throughout the study. The location effect was highly significant, which indicates that (as expected) vehicle speeds decreased on the approach to the taper. However, neither the taper length effect nor any of the other effects or interactions shown in Table 3 had a significant effect on vehicle speed.

Similar speed data were obtained at site 2, except that the influence of funneling and lane-width reduction was not considered. The construction activity at site 2 involved a lane closure followed by a traffic diversion (crossover) through a median opening of a multilane, divided urban arterial street. Speed data were collected at two locations in the crossover taper: L1 = 8 m (25 ft) from the beginning of the crossover taper and L2 = 23 m (75 ft) from the beginning of the crossover taper. An analysis of variance of the factors' taper length, time of day, and speed-measurement location found that the mean speed when the proposed taper was used was significantly higher than the mean speed when the standard taper was used. However, the absolute difference in mean speeds was less than 1.6 km/h (1 mph) [39 km/h (24.40 mph) versus 37 km/h (23.38 mph)].

At site 3, the proposed taper was compared with the existing, shorter-than-proposed taper. The construction activity at site 3 was similar to that at site 2, which involves a crossover through a median opening of a multilane, divided urban arterial street. Speed measurements were made at three locations: L1 was approximately 152 m (500 ft) before the taper, L2 was approximately 131 m (430 ft) before the taper, and L3 was at the crossover point. An analysis of variance of the speed data found that the three major factors (taper length, time of day, and location of speed measurement) were all significant, as were several of the interaction terms. The speeds with the existing shorter-than-proposed taper were significantly greater than the speeds with the proposed taper [55 km/h versus 59 km/h (34.33 mph versus 36.53 mph)]. The other significant factors and interactions indicate that the pattern of speed change on the approach to the zone is influenced by both the taper length and the time of day.

A final comparison of speeds for the standard and proposed taper lengths was made at site 4. This site involved the closure of the two left lanes of one direction of travel on a 6-lane divided arterial street. Speed measurements were made at three locations: L1 was approximately 275 m (900 ft) before the taper, L2 was near

Table 2. Summary of results.

Site	Design Speed (km/h)	Experiment	Time of Day	Mean Speed (km/h) Location 1	Location 2	Location 3	Erratic Maneuver Rate (Erratic Maneuver/100 Vehicles)	Conflict Rates (conflicts/100 vehicles) Slow Moving Conflicts	Previous Conflicts	Slow-To-Weave Conflicts	Right Turn Conflicts	Weave Conflicts	Encroachment Rate (Encroachments/100 Vehicles)
1	50	US-1—Proposed taper length, no funneling or lane width reduction	Day	71.0	66.3	56.2	0.19	0.19	8.00[a]	1.52[a]	0.13[a]	1.33[a]	NA
			Night	67.8	65.5	54.9	0.097	0.29	0[a]	0.68[a]	0.19[a]	1.84[a]	NA
		US-3—Proposed taper length, funneling and lane width reduction present	Day	71.3	66.8	52.8	7.63	7.02	1.49[a]	1.96[a]	0[a]	1.22[a]	NA
			Night	70.0	62.8	52.6	18.06	4.46	3.08[a]	2.44[a]	0[a]	0.96[a]	NA
		US-5—Standard taper length, no funneling and lane width reduction	Day	71.3	67.8	58.9	2.06	7.62	1.03[a]	0.79[a]	0[a]	1.11[a]	NA
			Night	70.0	66.3	57.6	8.68	5.71	0.95[a]	0.95[a]	0[a]	0.12[a]	NA
		US-6—Standard taper length, funneling and lane width reduction present	Day	69.7	66.0	54.9	4.79	7.14	2.00[a]	1.05[a]	0.17[a]	0.61[a]	NA
			Night	70.0	67.1	55.0	11.7	6.67	1.55[a]	0.48[a]	0[a]	0[a]	NA
2	45	1—Proposed taper length	Day	39.1	39.1	NA	7.46	2.99	1.09	3.49[a]	0.73[a]	3.17[a]	0.08[a]
			Night	39.3	39.6	NA	9.93	2.20	1.06	2.99[a]	0[a]	1.87[a]	0.56[a]
		2—Standard taper length	Day	36.2	38.0	NA	4.58	5.13	0.74	0[a]	0.96[a]	0[a]	0[a]
			Night	37.8	38.5	NA	9.12	4.21	0.90	0[a]	0.76[a]	0[a]	1.14[a]
3	50	1—Proposed taper length	Day	61.0	56.0	48.8	1.25	4.23	0.76	4.23	0.21	2.36[a]	0[a]
			Night	60.0	52.3	45.7	2.23	3.55	1.11	3.85	0.20	1.93[a]	0[a]
		2—Existing taper length	Day	57.0	62.0	48.5	13.58	3.78	1.22	0.07	0.54	0[a]	0[a]
			Night	58.6	58.7	46.8	12.72	4.16	0.59	0.12	0.12	0[a]	1.43[a]
4	72	1—Proposed taper length	Day	68.6	74.0	62.3	1.68	1.85[a]	0.43[a]	0.45	0[a]	0.96	NA
			Night	70.5	72.9	63.7	1.83	1.69[a]	0[a]	0.87	0[a]	0.19	NA
		2—Standard taper length	Day	71.8	74.7	59.6	2.16	2.03[a]	0.63[a]	1.34	0[a]	0.61	NA
			Night	69.5	69.4	60.2	3.26	1.70[a]	0.19[a]	0.75	0[a]	0.39	NA

Note: 1 km/h = 0.62 mph.
[a]These data were not included in the analyses of variance.

Table 3. Site 1: analysis of variance of speeds.

Source	df	Sum of Squares	Mean Squares	F-Ratio
Time (t)	1	4.17	4.17	9.07
Taper (T)	1	4.00	4.00	8.70
Funneling (F)	1	3.84	3.84	8.35
Location (L)	2	345.64	172.82	375.70[a]
tT	1	0.88	0.88	1.91
tF	1	0.32	0.32	<1
tL	2	0.81	0.41	<1
TF	1	0.14	0.14	<1
TL	2	2.43	1.22	2.65
FL	2	3.88	1.94	4.22
tTF	1	0.74	0.74	1.61
tTL	2	0.42	0.21	<1
tFL	2	0.34	0.17	<1
TFL	2	0.48	0.24	<1
Residual (tTFL)	2	0.91	0.46	

[a]Significant at the $\alpha = 0.05$ level.

the beginning of the taper, and L3 was near the end of the taper. In the analysis of variance, all three factors were significant, as were all three two-way interactions. The proposed taper speeds were significantly greater than the standard taper speeds [67 km/h versus 68 km/h (41.95 mph versus 42.67 mph)]. Again, the absolute difference in speeds between the two tapers was less than 1.6 km/h. In addition, the significant difference was due almost entirely to the speeds at location L3. The speeds for the standard and proposed tapers were statistically indistinguishable at locations L1 and L2.

Traffic Conflicts and Erratic Maneuvers

A comparison of the slow-moving-vehicle conflict rates for the standard and proposed taper lengths was made at site 1. The following table illustrates the comparative conflict rates per 100 vehicles at this site. The analysis found extremely low conflict rates both during the day and at night for the proposed taper formula in the absence of funneling or lane-width reduction. The other combinations tested (which included either the standard taper formula or the presence of funneling or both) had much higher traffic conflict rates.

Taper Length	Conflicts/100 Vehicles Day	Night
Proposed formula, no funneling	0.19	0.29
Proposed formula, funneling	7.02	4.46
Standard formula, no funneling	7.62	5.71
Standard formula, funneling	7.14	6.67

The erratic maneuver rates measured at site 1 are summarized below. The results of the erratic maneuver analysis are similar to the results of the conflict analysis for site 1. The erratic maneuver rate is very much lower for the proposed taper length in the absence of funneling than for any other combination.

Taper Length	Erratic Maneuvers/100 Vehicles Day	Night
Proposed formula, no funneling	0.19	0.10
Proposed formula, funneling	7.63	18.07
Standard formula, no funneling	2.06	8.68
Standard formula, funneling	4.79	11.68

At site 2, the standard and proposed tapers were compared with respect to both slow-moving-vehicle and previous conflict rates. An analysis of variance found no significant difference in previous conflict rate between the standard and proposed taper lengths, but the slow-moving-vehicle conflict rate was significantly greater for the standard taper length than for the proposed taper length.

The erratic maneuver rate at site 2 was found to be significantly higher at night than during the day. However, no statistically significant difference was found between the erratic maneuver rates for the standard and proposed taper lengths.

At site 3, the existing shorter-than-proposed taper length was compared with the proposed taper length with respect to slow-moving-vehicle conflicts, slow-to-weave conflicts, right-turn conflicts, and previous conflicts. The only statistically significant difference was found for the slow-to-weave conflicts, which were significantly higher with the proposed taper than with the shorter taper [4.0 versus 0.1; $F(1,26) = 75.34$]. In contrast, the erratic maneuver rate was much greater with the existing taper than with the proposed taper [13.6 versus 1.7; $F(1,26) = 205.06$]. It appears that at this site the proposed taper length eliminates erratic maneuvers but only at the expense of causing heretofore nonexistent slow-to-weave conflicts.

The standard and proposed taper lengths were compared at site 4 with respect to slow-to-weave conflicts, weave conflicts, and erratic maneuvers. No statistically significant differences were found.

Encroachment Rates

The effect of taper length on vehicle encroachments on the highway centerline was investigated at sites 2 and 3. After the proposed taper length was in place at site 2, 36 trucks and 1767 passenger vehicles were observed. Of these vehicles, only 1 truck and 4 passenger vehicles encroached on the highway centerline. During the daytime testing of the standard taper length at site 2, no encroaching passenger vehicles or trucks were recorded on the placement switches. During the night experiments, the lateral placement switches were not in use, but random visual observations of 200 vehicles revealed that approximately 4 percent of the vehicles traveled on or over the centerline. No encroaching trucks or buses were observed.

At site 3, no encroaching vehicles were observed during the daytime or nighttime periods when the proposed taper length was in place or during the daytime when the existing, shorter-than-proposed taper length was in place. During the nighttime sampling period of the existing taper length, 12 of 841 passenger vehicles were recorded encroaching on the centerline. None of the trucks and buses observed at this site was recorded as encroaching.

SUMMARY AND CONCLUSIONS

The study presented in this paper dealt with a proposed new taper length formula that yields shorter tapers than the standard formula, $L = WS$. Concern has been expressed that the new formula would result in more hazardous traffic operations. Speed and other measurements were performed at four sites, day and night, for a variety of design speeds and taper lengths. Altogether, nearly 20 000 vehicles (including 340 trucks and 17 buses) were observed and 13 000 speed measurements were obtained.

In general, speeds were slightly higher for the shorter-length tapers. At site 1, speeds did not differ significantly between the two tapers. At site 3, the very short taper produced significantly higher speeds than did the proposed taper. The speeds with the very short taper also showed a sudden decrease near the end of the taper. The more moderate decrease in speeds for the longer taper lengths could be associated with the fact that at sites 2 and 3 the longer tapers restricted traffic to one lane sooner than did the shorter tapers. In all cases, where a significant difference in traffic speeds was found, the absolute difference in mean speed was less than 1.6 km/h (1 mph).

Results of the erratic maneuver analysis were mixed. At site 2, the erratic maneuver rate did not vary between the standard and proposed taper lengths. At site 3, the very short taper had a higher erratic maneuver rate than did the proposed taper length. This result is compatible with the sudden drop in speed observed at site 3. At site 1, the taper effect was dependent on both the level of funneling and time of day. No site showed that the proposed taper created more erratic maneuvers than did the standard-length taper.

At site 1, only the proposed taper length in combination with the absence of funneling depressed the slow-moving conflict rate. At site 2, the slow-moving conflicts were greater under the standard taper length. This result is compatible with the lower speeds under the standard taper. Sites 3 and 4 showed no significant effects on slow-moving conflict rates. No site showed that the proposed taper created more slow-moving conflicts than did the standard-length taper.

Only site 3 showed a significant slow-to-weave conflict rate effect. Use of the proposed taper length rather than the shorter taper length increased slow-to-weave conflicts. This result may have been due to the fact that one more lane was closed during the proposed taper experiment than during the existing condition experiment. Also, at site 3, the increase in slow-to-weave conflict rate was accompanied by a significant decrease in erratic maneuver rate.

The placement switches at sites 2 and 3 did not indicate that trucks or buses were encroaching on adjacent lanes under the proposed taper. The number of encroaching passenger vehicles did increase under the very short existing taper at site 3 during the night measurements. No encroaching vehicles were observed during the day measurements, but 12 of 841 vehicles were observed encroaching during the night measurements.

In summary, the analyses do not imply that the proposed taper lengths are more hazardous than the standard taper lengths. In no instance was the erratic maneuver rate significantly higher with the proposed taper than with the standard or existing taper and at one site it was less (this site had an existing shorter-than-proposed taper). Likewise, slow-moving conflict rates were never greater with the proposed taper. Only at one site were slow-to-weave conflicts higher under the proposed as compared with the existing taper—at the site with the shorter-than-proposed taper. At three sites average speeds differed significantly with taper length, but by small magnitudes. At each of these three sites, speeds were higher when the shorter tapers were used. There was no indication that the proposed taper lengths resulted in a greater number of passenger vehicle or truck encroachments on adjacent lanes.

As a result of this field evaluation of the operational effects of taper length, the Federal Highway Administration (FHWA) and the National Advisory Committee on Uniform Traffic Control Devices (NAC) have approved the proposed taper formula for inclusion in the MUTCD (3). The proposed taper formula [$L = WS^2/157.5$ ($L = WS^2/60$, when S is in mph)] should be used to compute taper length on urban, residential, and other streets where the posted speeds are 65 km/h (40 mph) or less. The standard taper length formula is retained for freeways, expressways, and all other roadways having a posted speed of 72 km/h (45 mph) or greater. Sections 3B-4, 3B-8, 3B-13, and 6C-2 of the MUTCD will be revised accordingly.

ACKNOWLEDGMENT

This paper is based on a study conducted by Midwest Research Institute as part of a study for the Federal Highway Administration. The findings and conclusions of this paper are our own, however, and do not necessarily represent the views of the Federal Highway Administration.

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Effect of Longitudinal Edge of Paved Surface Drop-Offs on Vehicle Stability

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The effect of edge of pavement drop-offs on vehicle stability is reported for 50 tests of professional drivers handling small-, medium-, and large-sized automobiles and pickup trucks off, along, and back onto drop-off heights of 38 mm (1.5 in), 89 mm (3.5 in), and 114 mm (4.5 in) at about 26.8 m/s (60 mph). Tests of two- and four-wheel drop-offs were conducted from an existing asphalt concrete shoulder onto both compacted soil and asphalt concrete surfaces. The drop-off heights had little effect on vehicle stability: steering wheel angles were generally 60° or less; vehicle roll angles were 10° or less. A significant jolt and accompanying front-end noise were experienced by the driver at the larger drop-off heights; there were no problems with vehicle alignment. Less than one wheel revolution was required for the first wheel to mount the drop-off heights. Varying amounts of front-wheel wobble caused mainly by an irregular drop-off edge were detected. There was virtually no deviation in vehicle trajectory as the vehicles remounted the drop-off edges, and the vehicles did not encroach into adjacent traffic lanes. Two nonprofessional drivers participated in a few supplementary tests. They had no difficulties driving over all three drop-off heights at 17.9-20.1 m/s (40-45 mph). The results of these tests were used to help evaluate the California maintenance standards in effect in 1974.

In 1974, the California Department of Transportation studied some highway accident cases in which a drop-off at the longitudinal edge of pavement was cited as a possible contributing factor.

This project was initiated

1. To determine the effects of longitudinal drop-offs along a highway and on the stability and controllability of vehicles traveling over the drop-offs at high speeds,
2. To establish maximum tolerable heights for drop-offs,
3. To verify current maintenance standards for allowable drop-off heights.

No attempt was made to study the surprise element in driver reactions to an unexpected drop-off condition.

A longitudinal drop-off exists along a highway when there is a difference in height between two adjacent surfaces, either between

1. Surfaces of a paved shoulder and the unpaved area alongside it,
2. Surfaces of a paved traveled way and an unpaved shoulder,
3. Surfaces of a paved traveled way and a paved shoulder, or
4. Surfaces of a portion of an existing traveled way with a newly paved blanket overlay and the remaining portion of the existing pavement.

Drop-offs created during construction, when new traffic lanes are added to existing traveled ways, were not considered for this study. These drop-offs generally exceed the maximum heights of 114 mm (4.5 in) used for this project, and sometimes approach several meters, depending on soil conditions at the construction site.

Drop-offs are generally caused by erosion and traffic wear. However, during a pavement blanket overlay operation, a drop-off is frequently caused because the paving equipment cannot pave the full width of the traveled way or traveled way and shoulder at one time. There is often a delay before all of the existing pavement can be brought up to the grade of the new pavement blanket.

Portions of the California Department of Transportation maintenance manual dated May 15, 1974, specified California's drop-off standards and are illustrated in Figure 1.

The highway departments from the states of Illinois, New York, Oregon, Texas, and Washington were contacted during the course of this project for their allowable drop-off standards and accident experience records. New York permitted drop-off heights ranging from 25 mm (1 in) maximum for expressways with volumes over 500 vehicles/h to 51 mm (2 in) maximum for state highways having one-way design volumes of less than 200 vehicles/h. The other states either had no published standards, required shoulders to be flush with the traveled way, or allowed maximum drop-offs of 51-76 mm (2-3 in). Only Oregon had accident records related to drop-off conditions. The records from Oregon combined all accidents due to chuckholes and drop-offs.

A Highway Research Information Service (HRIS) literature search was made prior to the initiation of this project. Before 1974, none of the research reported had been conducted to determine whether longitudinal drop-offs cause vehicle stability problems.

Full-scale tests have been conducted by the California Department of Transportation (1, 2) and the Texas Transportation Institute (3) on the effects of vehicles climbing up over curbs at various angles. These tests were conducted on curbs with heights ranging from 152-305 mm (6-12 in) and also included a few tests over a sloping 102-mm (4-in) high curb. It was concluded that these tests did not apply to drop-off conditions of interest in this study, which was concerned with near-vertical drop-off heights less than 125 mm (5 in).