EVALUATION OF BREAKAWAY LIGHT POLES FOR USE IN HIGHWAY MEDIANS

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Crash tests were conducted to determine the impact behavior of median-mounted light poles and secondary collisions of vehicles striking downed poles on a traffic lane. A relative hazard index was developed to describe the relative hazard created by the proximity and frequency of light poles. It was concluded that a 20-deg impact by a 2,900-lb vehicle at 45 mph would not cause a pole to encroach on the opposing traffic lane if the median is 40 ft wide. A 4,000-lb vehicle impacting at 25 deg and 60 mph would cause a pole to encroach approximately 11 ft into the opposing lane. Under both conditions, the impacting vehicle would cross into the opposing lanes and might be more of a hazard than the poles themselves. A medium-sized vehicle impacting a downed pole within the traffic lane presents no more hazard than the original impact. From a relative hazard standpoint, median-mounted luminaire systems produce less hazard than house-side systems for median widths of 30 ft or greater.

•AS substantial mileage of the Interstate Highway System was being completed, there arose a need for safer and more efficient methods of lighting those facilities. Previous methods had consisted of relatively low luminaire mounting heights and frequent spacings with the supports located close to the roadway edge on rigid bases. These practices were acceptable for the low-operating speeds and volumes found on city streets but were unacceptable for the high-speed, high-volume characteristics of the freeway. The low mounting heights and frequent spacings produced uncomfortable environments for drivers as they passed through "hot spots" and "dark spots" on the roadway (1). The frequent spacings and location of the supports close to the roadway edge on rigid bases produced even more unacceptable environments. Frequent collisions with the supports by out-of-control vehicles resulted in severe vehicle damage and injury or death to the occupants (2).

The advent of higher output light sources provided partial solutions to the unacceptable conditions. Higher mounting heights with corresponding longer spacings and setbacks from the roadway were possible with the higher output light sources (3). This provided for a reduction in the "ladder" effect created by the "hot and dark spots." There remained, however, the potential for vehicle-support impact.

A similar problem had already been encountered with roadside signs mounted close to the roadway edge. This problem was successfully solved through the development and use of sign supports that would shear or break away when struck by an errant vehicle (4). Success with the breakaway sign supports led to the development of similar techniques for light poles.

Slip joints, cast aluminum transformer bases, cast aluminum inserts, notched bolt inserts, progressive-shear bases, and cast aluminum flanged bases have all been used with a high rate of success (2). These devices have provided for great flexibility in the location of light poles.

As a result of the safer supports, median-mounted luminaires have become very popular for the illumination of freeway facilities. Quality of illumination provided by this location and economy have contributed to the popularity. Objection has been voiced, however, to the use of median mountings where the height of support exceeds the median width. This objection has been based on the premise that secondary collisions may occur with a downed pole occupying a traffic lane. This report is in response to this objection.

STUDY OBJECTIVES

The objectives of this research are to investigate the impact behavior of median-mounted light poles and the behavior of secondary vehicle-support impact and to develop a hazard index to describe the relative hazard created by the proximity and frequency of light poles.

DETAILS OF TESTS

Three vehicle crash tests were conducted on 50-ft double-mast arm light poles with frangible transformer bases. The first two tests simulated accidents in which vehicles ran off the road and struck the breakaway supports. The third test simulated an accident in which an oncoming vehicle ran over a light pole that had been knocked into the traffic lane by a second vehicle that had left the opposing roadway.

In the first two tests, the vehicles were equipped with accelerometers attached to each longitudinal frame member. The tests were recorded on documentary and high-speed films for time-displacement analysis. The third test was recorded photographically, but no electronic accelerometers were used. Instead, a mechanical device called an Impact-O-Graph was used to measure triaxial accelerations.

In the first two tests, the poles and mast arms were oriented at angles to the direction of vehicle travel. The orientations were such that a vehicle would be veering to the right of its normal traffic lane in these tests. The supports were oriented in this manner because of space and hardware restrictions. However, the double-mast arm supports are designed for median installations and would normally be exposed to impacts by vehicles running off the road to the left of the normal traffic flow. Because the supports and the front ends of the vehicles are symmetrical, the response of the poles in such impacts is a mirror image of that in an impact at the same angle from the other side. Therefore, the final positions of the supports are shown in the drawings as they would have been if struck in the same manner by a vheicle encroaching the median. For purposes of these simulations, a 40-ft wide median (including shoulders) has been assumed.

Test LS-1

Test LS-1 simulated a relatively lightweight vehicle striking the support at a 45-mph speed and a 20-deg angle to the direction of the roadway. The octagonal galvanized pole was mounted on a frangible aluminum transformer base (Fig. 1).

The vehicle contacted the pole 18 in. to the right of the vehicle's centerline, but the base shattered, allowing the support to rotate up and clear the vehicle as intended. Sequential photographs of the test are shown in Figure 2. Figure 3 shows the fragmented base after the test. The front of the vehicle before and after the impact is shown in Figure 4. The vehicle sustained a residual deformation to the right front of 0.6 ft.

Table 1 gives the pertinent vehicle data. The speeds from the films are average speeds over about 3-ft intervals preceding contact and following the interval of accelerometer activity. The accelerometer data given in Table 1 are the average of the right- and left-frame accelerometers.

The final position of the light pole in relation to its original position and a hypothetical 40-ft median strip is shown in Figure 5. In this case, the support would have remained within the median. However, the errant vehicle entered the oncoming traffic lanes without significantly altering its course. The only conclusion that can be drawn from this is that, if the vehicle was traveling straight at an angle to the road upon impact with no driver control and the median was flat and level, then such an impact would cause encroachment of the oncoming traffic lanes by the errant vehicle.

Test LS-2

Test LS-2 was similar to LS-1 except that the vehicle was heavier, the impact angle was increased to 25 deg, and the impact speed was 60 mph instead of 45 mph.

Figure 1. Light pole base before test LS-1.

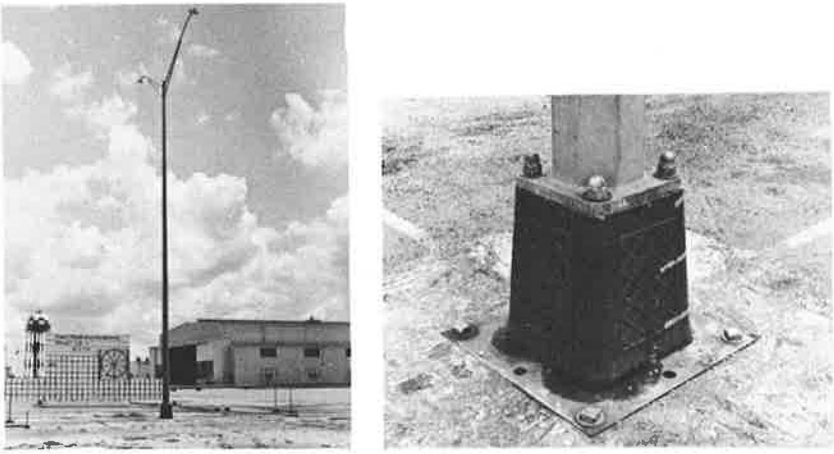


Figure 2. Test LS-1.

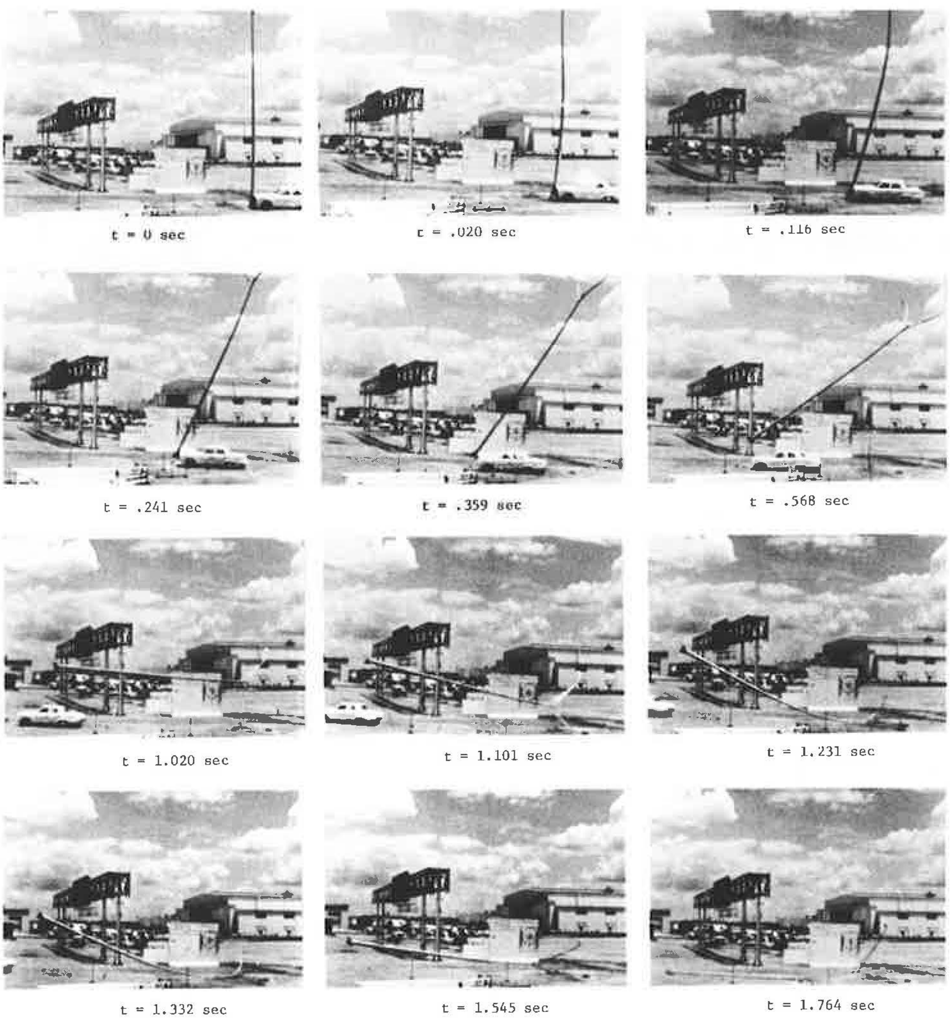


Figure 3. Frangible transformer base after test LS-1.

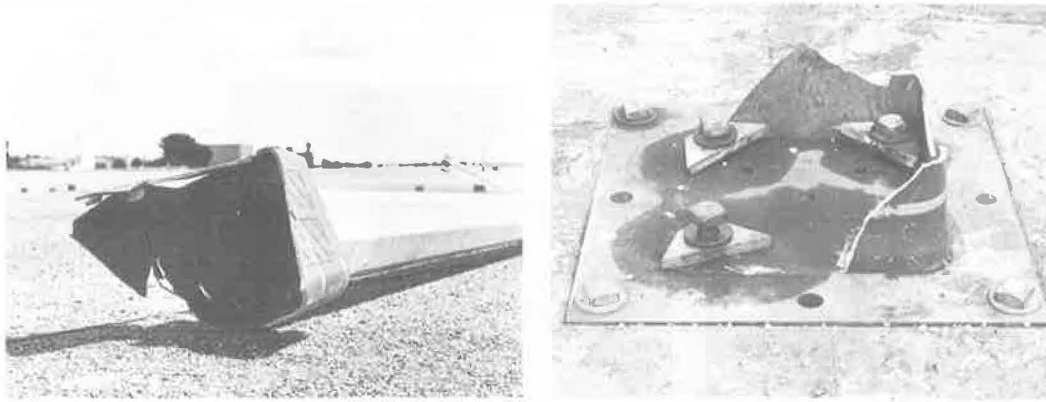


Figure 4. Front of vehicle before and after test LS-1.

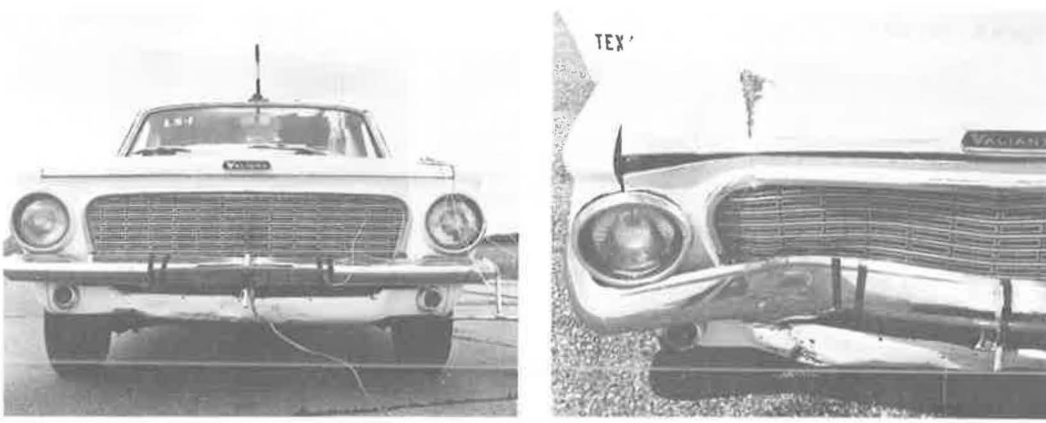


Table 1. Tests LS-1 and LS-2 data.

Factor	LS-1	LS-2
Vehicle		
Year	1963	1961
Make	Plymouth	Chevrolet
Weight, lb	2,900	4,040
Angle of approach, deg	20	25
Residual deformation, ft	0.6	1.5
Film data		
Initial speed, ft/sec	67.2	87.6
Initial speed, mph	45.8	59.7
Final speed, ft/sec	60.7	78.4
Final speed, mph	41.4	53.3
Average longitudinal deceleration[a], g	2.0	4.1
Change in momentum[b], lb-sec	585	1,155
Accelerometer data		
Maximum longitudinal deceleration, g	14.4	8.2
Average longitudinal deceleration, g	2.5 over 0.110 sec	3.6 over 0.072 sec

[a]$(V_i^2 - V_f^2)/2gS$. [b]$\Delta P = (W/g)(\Delta V)$.

The cast aluminum transformer base (Fig. 6) shattered as expected, and the pole rotated up and cleared the vehicle as the vehicle continued on its course. Sequential photographs of the test are shown in Figure 7; the shattered base is shown in Figure 8.

The front end of the vehicle had a residual deformation of 1.5 ft (Fig. 9). The increased damage is primarily due to the higher impact speed.

The vehicle data given in Table 1 show that the significant deceleration period was about two-thirds as long as that in test LS-1, which was conducted at a lower speed.

Figure 10 shows the final position of the light pole. If the pole had been mounted in the center of a 40-ft median, the base after the test would have projected 11 ft horizontally into the oncoming "inside" traffic lane at an angle of 33 deg to the roadway. Under these simulated conditions, the vehicle would have crossed the oncoming lanes.

Test LS-3

Test LS-3 was designed to determine the behavior of an automobile striking a "downed" light pole under conditions that would have resulted from a crash such as that of test LS-2. The support from test LS-2 was placed in such a way that the 12.5-ft wide concrete slabs that make up the test apron would simulate the oncoming inside traffic lane. That is, the base extended 11 ft into the simulated lane at an angle of 33 deg and pointed toward the approaching test vehicle as shown in Figures 11 and 12. The test vehicle, which was traveling in the center of the simulated traffic lane, struck the support at 61 mph, passed over it, and continued virtually straight ahead as shown in Figure 13. Figures 14 and 15 show the support after the test; Figure 16 shows the path of the vehicle.

Table 2 gives the film and Impact-O-Graph data on the vehicle. The Impact-O-Graph, being primarily mechanical, is not as accurate as electronic devices for measuring accelerations of this nature, but it has been found to give representative data. Note that the average decelerations (or accelerations) are low, but the peak accelerations are substantial in the vertical and transverse directions. However, these peaks are of short duration, and the vehicle exhibited no tendency to spin out or otherwise deviate significantly from its original path except for a gradual curvature to the left. Both the left-front and right-rear tires were deflated by the impact.

The light pole was pushed around to an angle of 85 deg to the roadway and extended 25 ft into the traffic lanes after the test. Note in Figure 13 that the vehicle did not contact the fragmented base but ran over the shaft only.

DISCUSSION OF TESTS RESULTS

The breakaway behavior of 50-ft double-mast arm light poles with frangible transformer bases is satisfactory under the conditions of the first two tests. The vehicles passed under the supports, after shearing them from their bases, and continued on essentially their original paths.

If the poles were installed in the center of a 40-ft median (including shoulders), a 20-deg impact by a 2,900-lb vehicle at 45 mph would probably not cause the pole to encroach on the opposing traffic lanes. However, in the single test under these conditions, the final position was marginal, the base of the support being 1 ft from the roadway. A 4,000-lb vehicle impacting at 25 deg and 60 mph causes the pole to encroach 11 ft into the opposing inside traffic lane. Both conditions allowed the vehicles to cross into the hypothetical traffic lanes, and this may be more of a hazard than the poles themselves.

If a medium-sized vehicle encounters a support in its traffic lane and strikes it with all wheels on the pole shaft (not straddling the base nor attempting to maneuver) at 60 mph, it may be able to continue straight ahead until control is regained. However, no firm conclusions can be drawn from one test. The support struck in such a manner would possibly be shifted into the adjacent traffic lane and thereby furnish a further hazard to other traffic.

Figure 5. Final position of light pole in test LS-1.

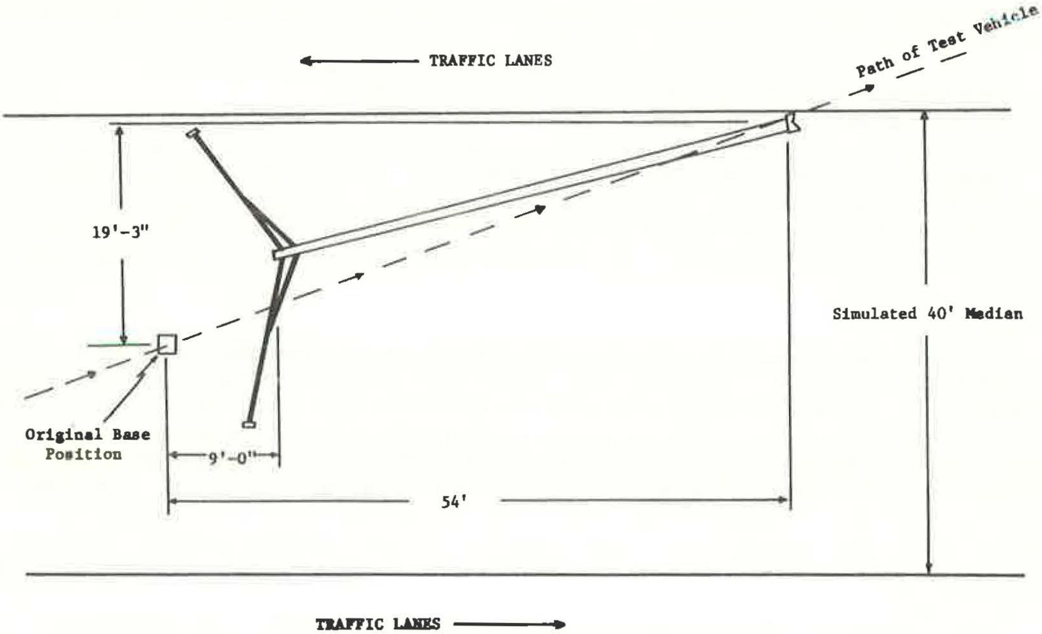


Figure 6. Light pole base before test LS-2.

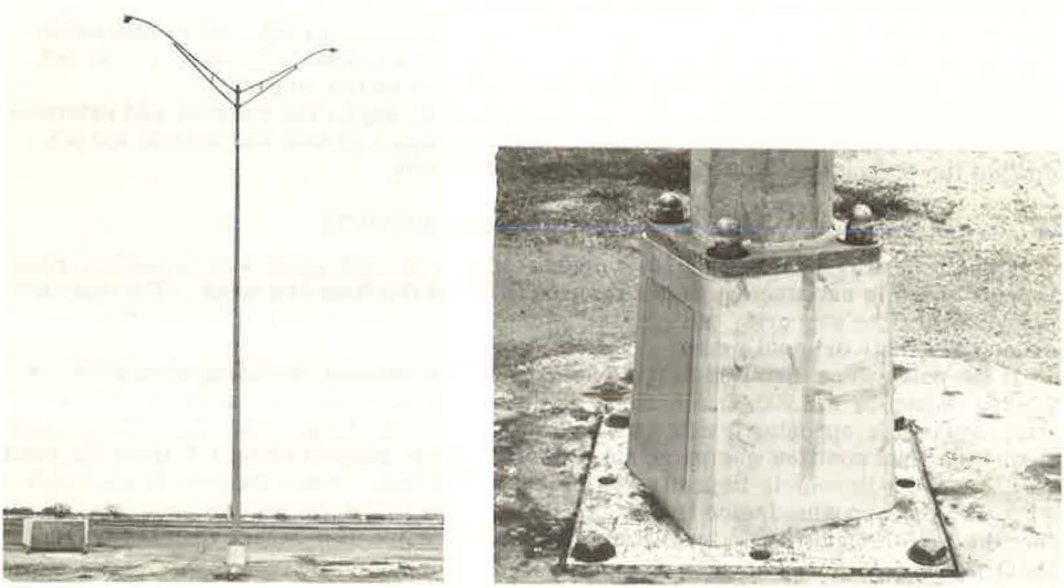


Figure 7. Test LS-2.

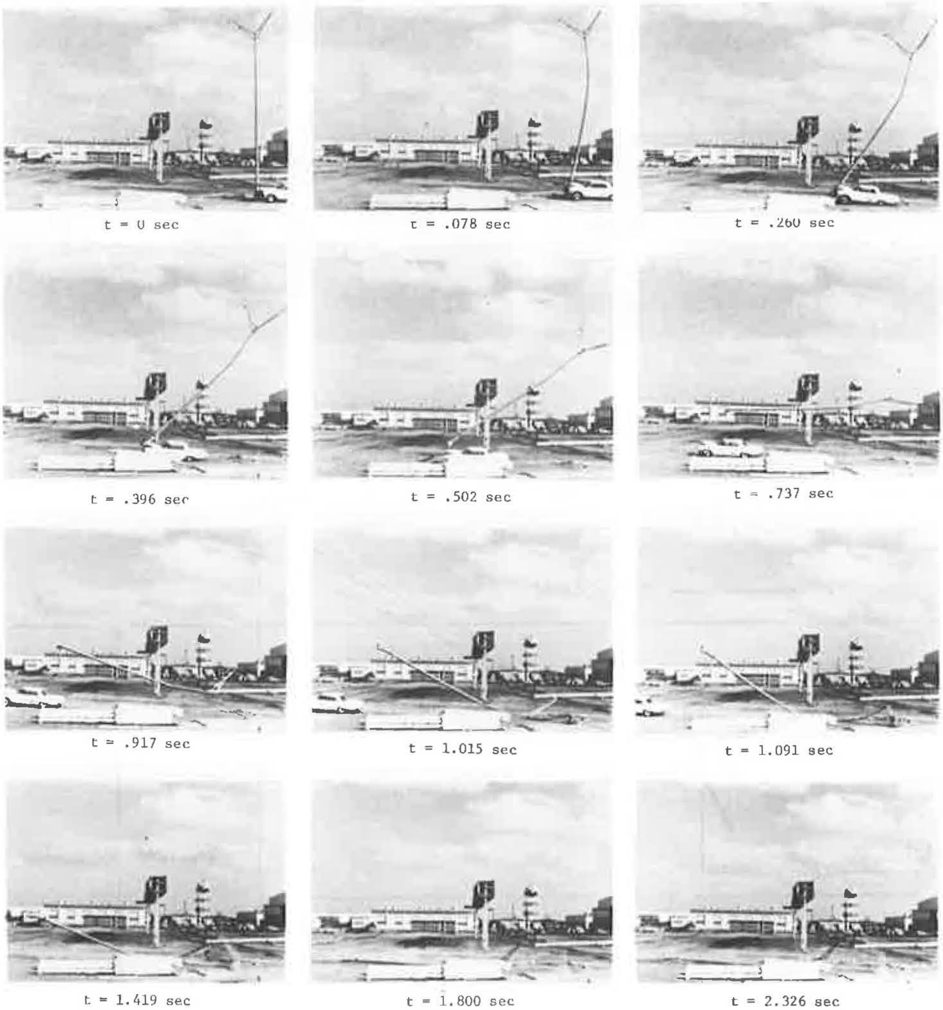


Figure 8. Frangible transformer base after test LS-2.

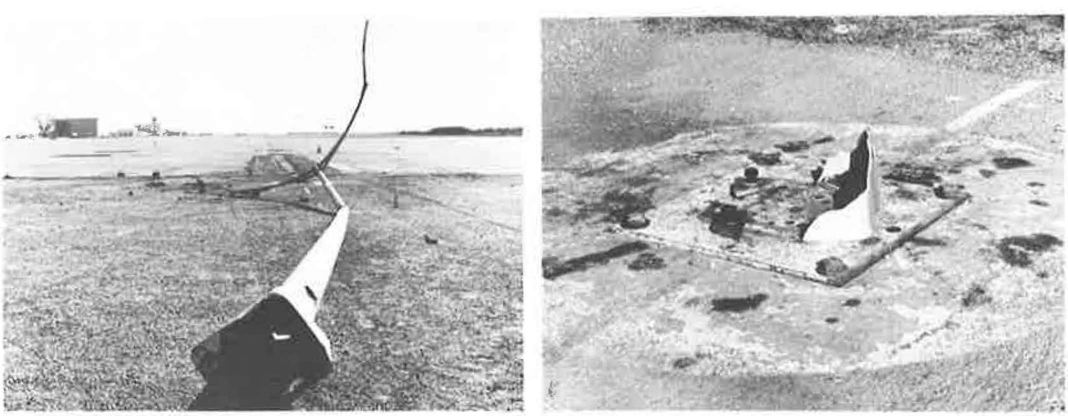


Figure 9. Front of vehicle before and after test LS-2.

Figure 10. Final position of light pole in test LS-2.

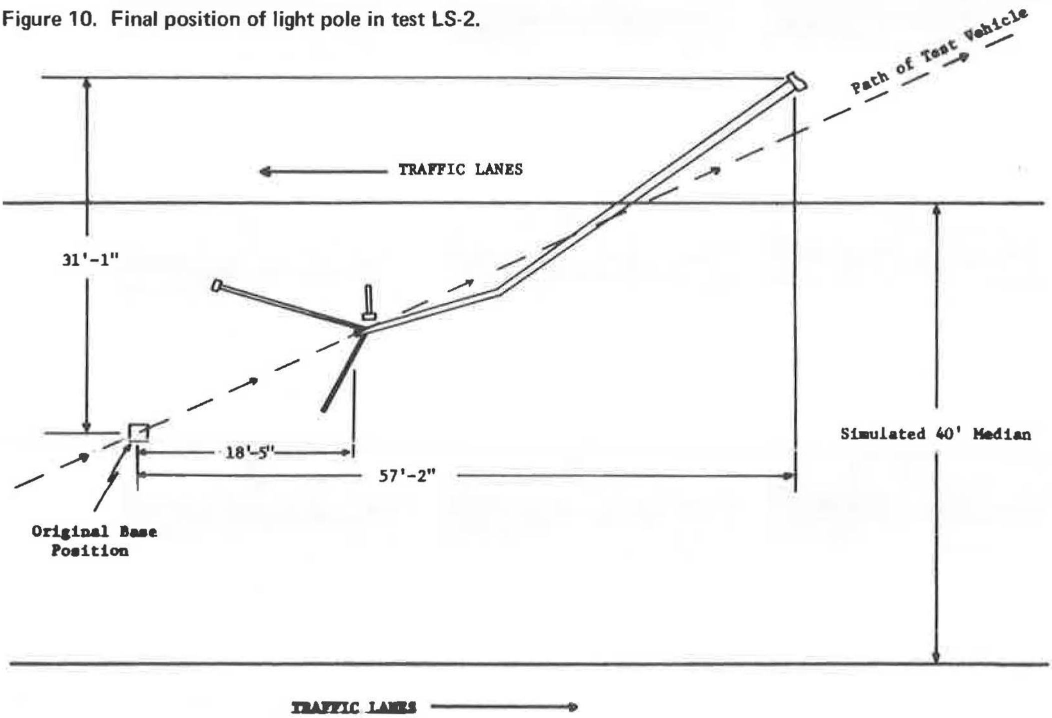


Figure 11. Light pole before test LS-3.

Figure 12. Position of light pole before test LS-3.

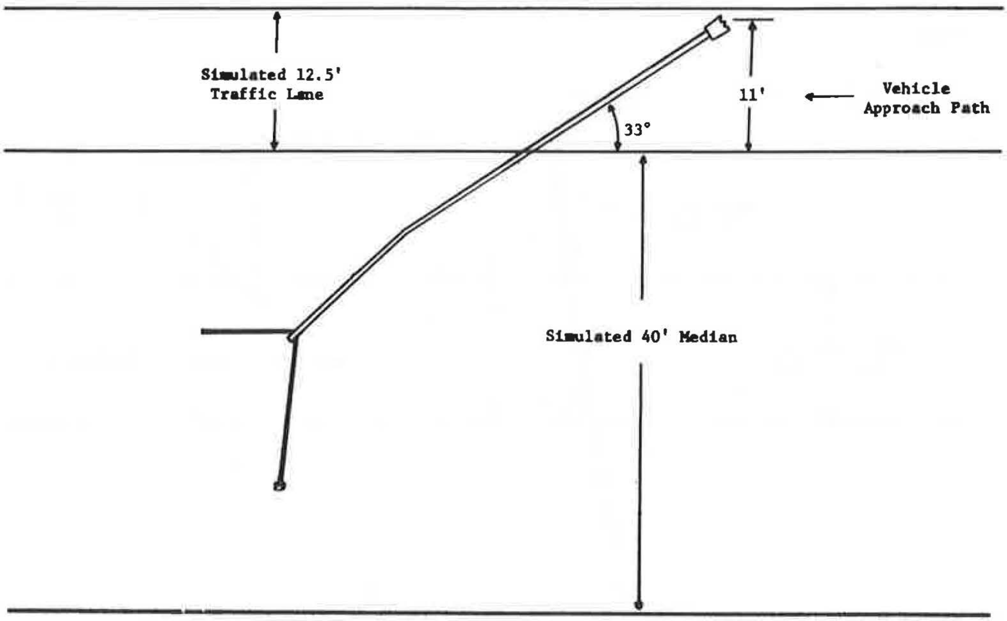


Figure 13. Test LS-3.

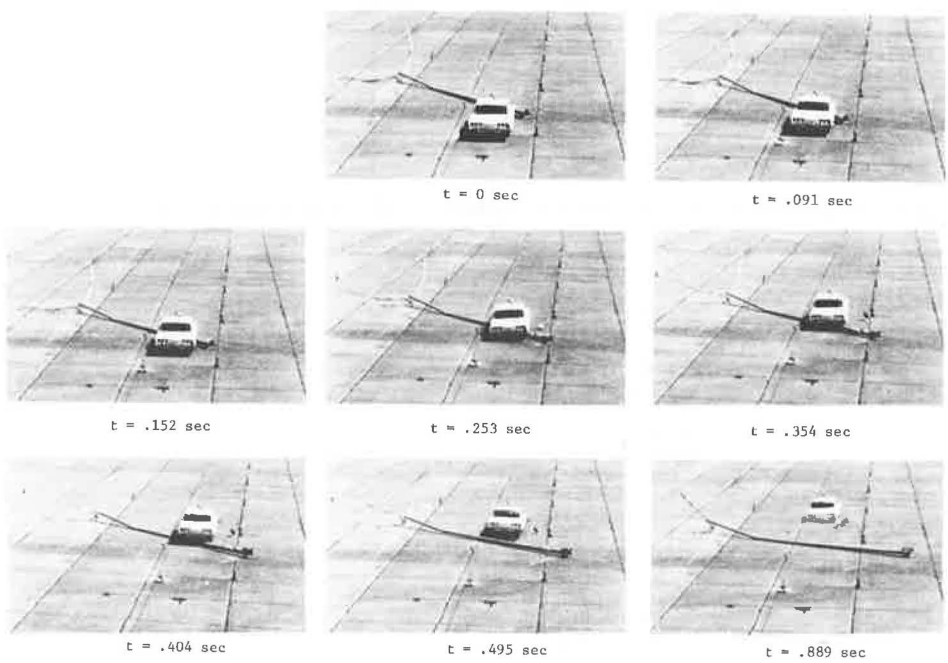


Figure 14. Light pole after test LS-3.

Figure 15. Position of light pole after test LS-3.

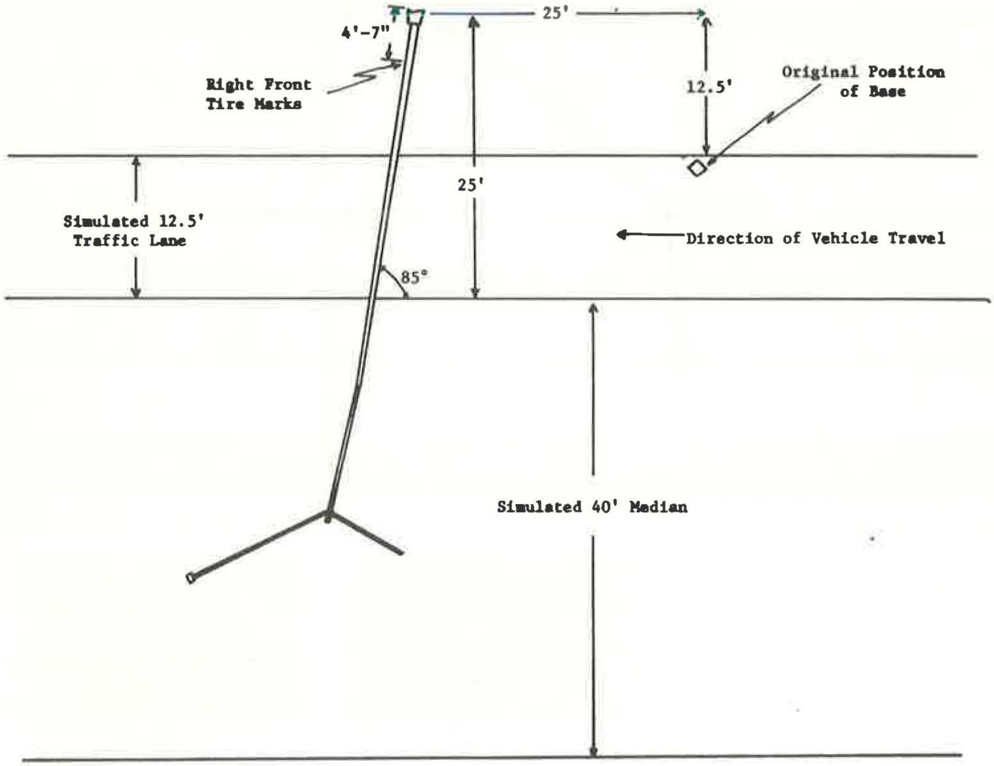


Table 2. Test LS-2 data.

Factor	LS-3
Vehicle	
Year	1963
Make	Chevrolet
Weight, lb	3,630
Film data	
Initial speed, ft/sec	89.6
Initial speed, mph	61.1
Final speed, ft/sec	84.1
Final speed, mph	57.3
Time in contact, sec	0.355
Average longitudinal deceleration[a], g	0.5
Impact-O-Graph data	
Longitudinal deceleration	
Maximum, g	3.4
Average, g	0.1
Time, sec	0.502
Vertical acceleration	
Maximum, g	13.5
Average, g	0.2
Time, sec	0.502
Transverse acceleration	
Maximum, g	13.5
Average, g	0.05
Time, sec	0.502

[a]$\Delta V/g\Delta T$.

DEVELOPMENT OF A RELATIVE HAZARD INDEX FOR LIGHT POLES

The purpose of this section is to formulate the procedure for determining a relative hazard index for alternative lighting systems on a typical freeway facility. Specifically, the relative hazard index describes the relative hazard created by the proximity and frequency of light poles.

The alternative lighting systems presented are basically median-mounted and house-side lighting systems at mounting heights of 30, 40, 45, and 50 ft at a 5:1 spacing-to-mounting height ratio. Each of the systems is shown in Figure 17.

Table 3 summarizes the data for each of the alternative lighting systems and presents the relative hazard index for a 44-ft median, a design of special current interest. A similar comparison can be made for any median width. This relative hazard index is computed as the product of the relative index of a vehicle impacting a light pole based on lateral distance from the traveled way, the relative number of hazards per unit length of roadway, and the relative number of traffic streams (directions) to which the light poles are exposed. To explain the source of each of these factors, reference is made again to Table 3. Column 5 gives the lateral distance of the support from the edge of the traveled way for each of the alternative designs. The two distances given for alternative designs 5 and 6 represent two supports in alternative design 5 and an offset situation in alternative design 6. Column 6 of Table 3 gives the percentage of probability that an errant vehicle will travel a sufficient lateral distance from the traveled way to become involved in a collision with a support. These values are based on frequently referenced data reproduced in Figure 18a from Hutchinson reported by Stonex (5).

Column 7 of Table 3 gives the estimated percentage of probability of secondary collisions caused by the light pole falling in an opposing traffic lane and being struck by an oncoming vehicle. The percentage of probability is determined on the basis that only supports struck at angles greater than 20 deg will fall in the opposing traffic lanes. Further, this effect is considered only for 45- and 50-ft supports. Shorter support lengths are assumed to always fall within the median. The percentage of probabilities was obtained from Figure 18b.

In test LS-3, in which a vehicle ran over a downed 50-ft steel light pole, there was strong evidence that the secondary collision was of no greater severity than the initial impact with the upright support. Therefore, the relative probability index of collisions (column 8) was determined by increasing the percentage of probabilities (column 6) by the estimated percentage of impact greater than 20 deg (column 7). The percentage of probability (column 6) actually used was a computed average.

In column 9, the relative frequency of exposure of a vehicle to light poles is computed using the 250-ft spacing of the 50-ft median-mounted system as unity.

Column 10 lists the exposure indexes based on the exposure of the traffic streams to light poles. The median-mounted systems can be struck from either direction, whereas the house-side systems can only be struck from one direction.

Column 11 represents the combined total hazard index (of a vehicular collision with a light pole) based on lateral distance from the roadway to the light role, the relative number of hazards per mile, and the exposure to traffic flows. It is obtained by computing the product of columns 8, 9, and 10.

For ease of interpretation, the total hazard index values of column 11 are converted to a base of unity by dividing all values by the smallest value in the column. These values, called the relative hazard index, are given in column 12.

RELATIVE HAZARD INDEX AND MEDIAN WIDTH

The relative hazard for various median widths was composed by making a similar analysis for a 50-ft median-mounted system in median widths ranging from 10 to 60 ft. The details of the analysis are given in Table 4.

It should be noted that column 5 of Table 4 contains the relative probability of a secondary collision occurring because of opposing traffic striking the downed support in the opposing traffic lane. This is based on test LS-2, a 4,000-lb vehicle striking a 50-ft support at 25 deg and 60 mph, in which the lateral translation of the pole base

Figure 16. Path of vehicle in test LS-3.

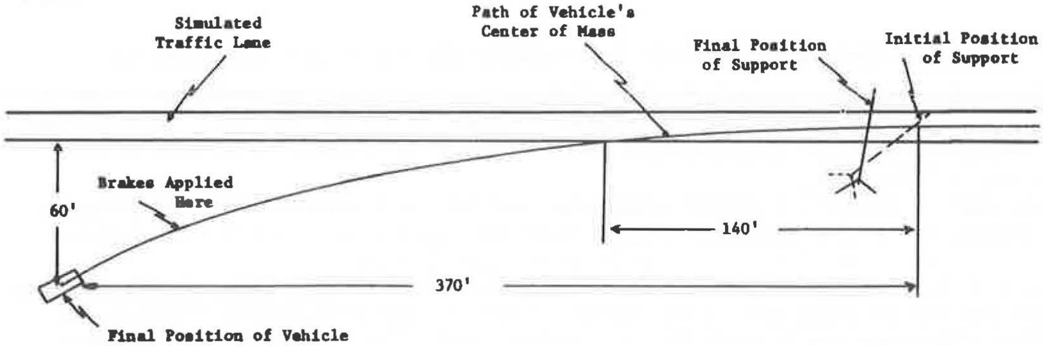


Figure 17. Light pole design systems.

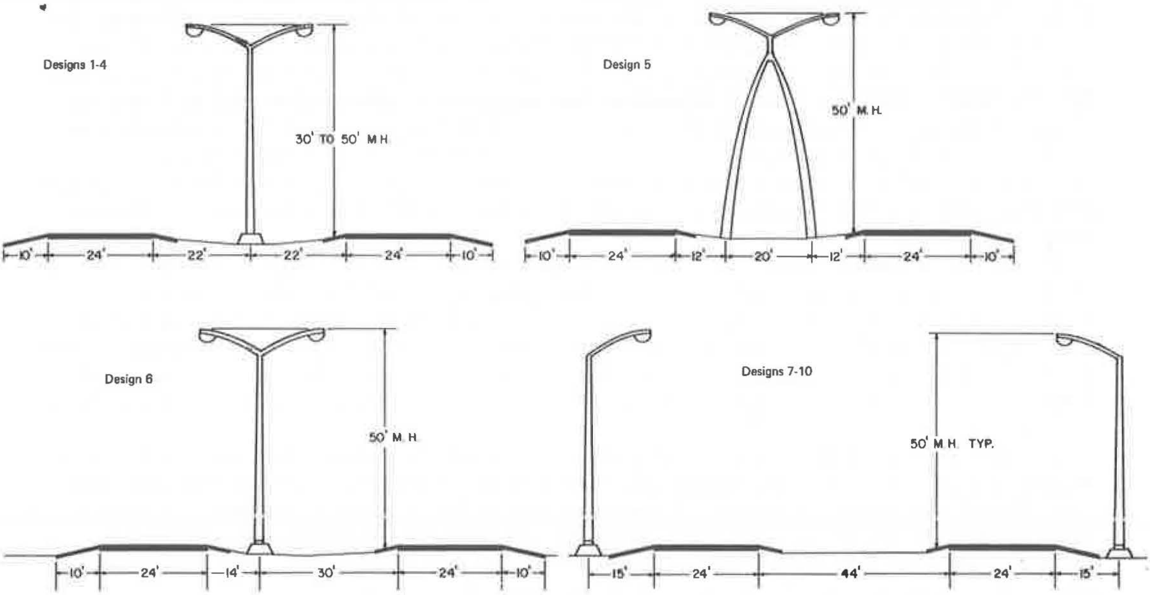


Table 3. Relative hazard index.

Alter- native Design (1)	Mount- ing Height of Lumi- naires (ft) (2)	Longi- tudinal Spac- ing of Light Pole[a] (ft) (3)	Loca- tion of Light Pole (4)	Dis- tance From Road- way to Light Pole (ft) (5)	Percent- age of Proba- bility[b] (6)	Esti- mated Percent- age of 20-deg Impact (7)	Relative Probability Index of Vehicle Collision With Light Pole (8)	Relative No. of Light Poles per 250 Ft (9)	No. of Traffic Streams Exposed to Light Poles (10)	Total Hazard Index (11)	Relative Hazard Index (12)
1	30	150	Median	22	22		0.22	1.66	2.00	0.730	1.58
2	40	200	Median	22	22		0.22	1.25	2.00	0.55	1.19
3	45	225	Median	22	22	5	0.231	1.11	2.00	0.513	1.11
4	50	250	Median	22	22	5	0.231	1.00	2.00	0.462	1.00
5	50	250	Median	12 32	55 9		0.32	2.00	2.00	1.280	2.77
6	50	250	Median	30 14	11 46	10	0.308	1.00	2.00	0.616	1.33
7	50	250	House- side	15	45		0.45	2.00	1.00	0.900	1.95
8	45	225	House- side	15	45		0.45	2.22	1.00	1.000	2.16
9	40	200	House- side	15	45		0.45	2.50	1.00	1.124	2.43
10	30	150	House- side	15	45		0.45	3.32	1.00	1.492	3.23

[a]5:1 spacing-to-mounting height ratio. [b]Based on Hutchinson's findings (5). [c]Assumes support may fall across two lanes.

Figure 18. Relation of cross section design and highway safety.

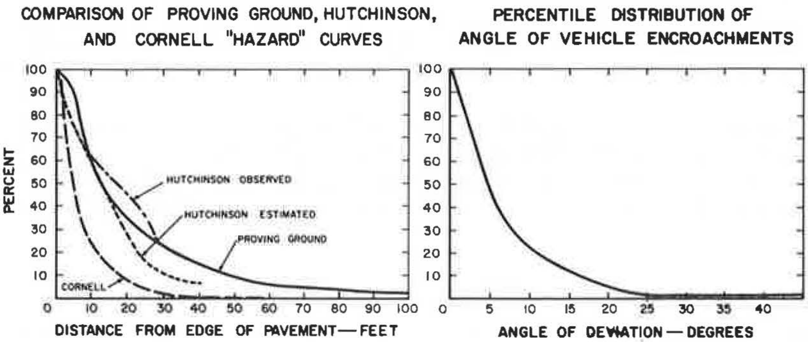
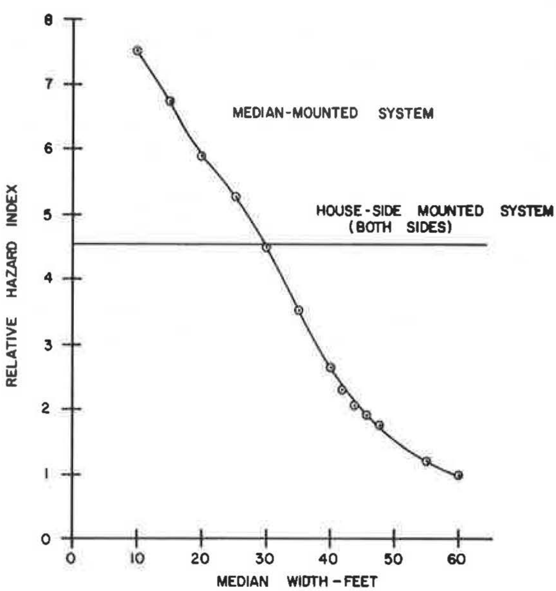


Table 4. Median width and relative probability index.

Location (1)	Median Width (ft) (2)	Distance From Roadway to Light Pole (ft) (3)	Percentage of Probability[a] (4)	Estimated Percentage of 20-deg Impact (5)	Relative Probability Index of Vehicle Collision With Light Pole (6)	No. of Traffic Streams Exposed to Light Poles (7)	Relative No. of Supports per 250 Ft (8)	Total Hazard Index (9)	Relative Hazard Index (10)
Median	60	30	11	—	0.110	2.00	1.00	0.220	1.00
Median	55	27.5	13	—	0.130	2.00	1.00	0.260	1.18
Median	48	24.0	18	5	0.189	2.00	1.00	0.378	1.72
Median	46	23.0	20	5	0.210	2.00	1.00	0.420	1.91
Median	44	22.0	22	5	0.231	2.00	1.00	0.462	2.10
Median	42	21.0	25	5	0.263	2.00	1.00	0.526	2.39
Median	40	20.0	28	5	0.294	2.00	1.00	0.588	2.67
Median	35	17.5	37	5	0.388	2.00	1.00	0.776	3.53
Median	30	15.0	45	10	0.495	2.00	1.00	0.990	4.50
Median	25	12.5	52	10	0.572	2.00	1.00	1.144	5.22
Median	20	10.0	59	10	0.650	2.00	1.00	1.300	5.91
Median	15	7.5	67	10	0.738	2.00	1.00	1.476	6.71
Median	10	5.0	75	10	0.825	2.00	1.00	1.650	7.50
House-side		15	45	—	0.45	1.00	2.22[b]	1.00	4.55

[a]Based on Hutchinson's findings (5). [b]Recommended spacing of 225 ft for house-side installations.

Figure 19. Relation of relative hazard index and median width.



was 31 ft. Given that an encroachment of more than 4 ft into a traffic lane may result in a collision, the estimated percentage of impacts greater than 20 deg was determined from Figure 18b.

Figure 19 shows a plot of the values for relative hazard index and median width for a median-mounted system and for a 50-ft house-side system with supports located 15 ft from the edge of the roadway on both sides. This comparison indicates that median-mounted lighting systems produce less hazard than house-side systems for median widths 30 ft or greater.

CONCLUSIONS

Based on the results of the three crash tests and development of the relative hazard index, the following conclusions are drawn:

1. The breakaway behavior of 50-ft double-mast arm light poles with frangible bases is satisfactory under the conditions of tests LS-1 and LS-2.
2. A 20-deg impact by a 2,900-lb vehicle at 45 mph would probably not cause a pole to encroach on the opposing traffic lane if the median is 40 ft wide (including shoulders).
3. A 4,000-lb vehicle impacting at 25 deg and 60 mph would cause a pole to encroach approximately 11 ft into the opposing inside traffic lane if the median is 40 ft wide (including shoulders).
4. Both conditions 2 and 3 would allow the impacting vehicle to cross into the opposing traffic lanes, and this may be more of a hazard than the poles themselves.
5. A medium-sized vehicle that encounters a support in its traffic lane and strikes it with all wheels on the pole shaft (not straddling the base nor attempting to maneuver) at 60 mph would probably be able to continue straight ahead until control is regained.
6. From a relative hazard standpoint, 50-ft high median-mounted light poles produce less hazard than house-side systems for median widths of 30 ft or greater.

ACKNOWLEDGMENTS

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The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

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