FULL-SCALE VEHICLE CRASH TESTS OF LUMINAIRE SUPPORTS

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•THE Federal Highway Administration (FHWA) Circular Memorandum of June 5, 1968, concerning breakaway luminaire supports, specified an allowable momentum change during a vehicle impact with a luminaire support of 1,100 lb-sec. This specification was derived from data and recommendations presented by Rowan and Edwards (1) and from tests conducted by the aluminum industry. Since that time, the use of pendulum tests has been requested because of its economy. A survey of the limited data available, comparing vehicle tests and pendulum tests, showed that the observed momentum change in a pendulum test may be less than half that found by a vehicle crash test on the same luminaire support. In recognition of this, another FHWA notice was circulated on November 16, 1970 (TO-20), which allowed a pendulum test to be substituted for a vehicle crash test. This notice set an allowable momentum change for pendulum tests of 400 lb-sec. It was recognized at that time that the specification was based on a very limited number of tests. FHWA therefore took the lead in setting up additional tests of luminaire supports that would better compare vehicle and pendulum test results.

The seven vehicle crash tests that were considered essential to this comparison (LS-1 through LS-7) were conducted during the months of February and March 1971. These tests are reported, evaluated, and compared with pendulum impact tests of identical luminaire supports conducted by Reynolds Metals Company (2). Two additional full-scale vehicle crash tests (LS-8 and LS-9), sponsored by the Union Metal Manufacturing Company, were conducted during April 1971. Further information concerning these nine tests can be found elsewhere (3, 4).

DESCRIPTION OF TESTS

The luminaire supports used in these tests were mounted on a 24-sq. in. by 2-in. thick baseplate that was in turn recessed into and bolted to a rigid concrete foundation. The mast arm of the supports extended to the west, and the test vehicle traveled from south to north. (A summary of descriptive features of the luminaire supports that were tested is given in Table 1.)

The test vehicles were towed with a cable and pulley arrangement. A quick-release mechanism was incorporated at the test vehicle attachment point to release the vehicle immediately prior to impact. A cable that was stretched alongside the vehicle path and threaded through an attachment to one of the front spindles of the test vehicle provided directional guidance.

All accelerometers were of the strain-gauge type, and all accelerometer signals were run through an 80-Hz low-pass filter. The accelerometers were mounted on the longitudinal frame members of the car; they measured acceleration in the longitudinal direction of the vehicle.

Three motion picture cameras were used to record each test event and to obtain time-displacement data. One high-speed camera was focused on the lower portion of the support and the impacting vehicle. The other high-speed camera recorded the entire scene. A documentary camera was panned to follow the vehicle.

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Table 1. Luminaire support characteristics.

Test No.	NEMA Test No.[a]	Pole Manufacturer	Aluminum Alloy and Temper: Shaft	Aluminum Alloy and Temper: Base	Support Height (ft)	Shaft Length (ft)	Shaft Wall Thickness (in.)	Shaft Base Diameter (in.)	Shaft Cap Diameter (in.)	Height Above Ground of Handhole Center[b] (ft)	Shoe Base Height (in.)
LS-1	3	Kerrigan	6063-T6	356-T6	35	32	0.250	8	4.5	1.2	3.5
LS-2	10	HAPCO	6063-T6	356-T6	40	37.2	0.250	10	6	1.5	5
LS-3	9	P&K	6063-T6	356-F	40	37.7	0.250	10	5.5	1.0	5
LS-4	10	HAPCO	6063-T6	356-T6	40	37.2	0.250	10	6	1.5	5
LS-5	4	P&K	6063-T6	356-F	40	37.7	0.188	10	5.5	1.0	5.5
LS-6	—	Kerrigan (HAPCO base)	6063-T6	356-T6	50.25	45.25	0.250	10	6	1.7	4[c]
LS-7	10	HAPCO	6063-T6	356-T6	40	37.2	0.250	10	6	1.5	5
LS-8	—	Union Metal	6063-T6		50	47.5	0.250	12	6.6	—	6
LS-9	—	Union Metal	Steel	Steel	45	38	11 gauge	9	5.1	—	—

[a]Ref. 2.
[b]Measurement was approximate; handhole was oriented opposite the impacted side of the pole.
[c]Four-inch shoe base was bolted to 6-in. pedestals.

Table 2. Test data.

Test No.	Vehicle	Vehicle Weight (lb)	Vehicle Residual Deformation (ft)	Film: Initial Speed fps	Film: Initial Speed mph	Film: Final Speed fps	Film: Final Speed mph	Change in Momentum: High-Speed Film (lb-sec)	Change in Momentum: Accelerometer (lb-sec)	Accelerometer Data: Maximum Deceleration (g)	Accelerometer Data: Average Deceleration and Time: g	Accelerometer Data: Average Deceleration and Time: msec
LS-1	1963 Plymouth	3,600	1.6	58.5	39.9	49.6	33.8	990	960	10.3	3.8	70
LS-2	1963 Plymouth	3,550	1.5	58.1	39.6	47.3	32.2	1,190	1,280	13.4	5.0	72
LS-3	1963 Plymouth	3,750	1.8	59.4	40.5	46.9	32.0	1,420	1,390	10.4	5.6	68
LS-4	1963 Plymouth	3,590	1.3	61.6	42.0	52.0	35.5	1,070	1,070	9.8	4.4	68
LS-5	1963 Plymouth	3,650	1.3	60.1	41.0	54.9	37.5	590	680	6.4	2.0	92
LS-6	1963 Plymouth	3,620	1.3	59.6	40.6	52.3	35.7	820	710	5.0	2.6	75
LS-7	1957 Cadillac	5,050	1.2	60.9	41.5	51.9	35.4	1,410	1,330	9.8	4.4	60
LS-8	1963 Chevrolet	3,650	1.7	56.8	38.7	36.5	24.9	2,300	2,165	18.8	7.6	90
LS-9	1963 Chevrolet	3,710	0.3	59.0	40.2	55.5	37.8	405	425	5.4	1.9	42

1963 Plymouths were used in Tests LS-1 through LS-6, a 1957 Cadillac in Test LS-7, and 1963 Chevrolets in Tests LS-8 and LS-9. These vehicles were instrumented with accelerometers on the longitudinal frame members. A dummy, restrained by a strain-gauged seat belt to determine seat-belt forces, occupied the driver's seat in all of the tests except LS-8 and LS-9.

Eight of the luminaire supports tested were made of Alloy 6063-T6 aluminum with Alloy 356 cast aluminum shoe bases welded on. In Test LS-6, the support and base were mounted on 6-in. tall frangible pedestals. A 9-in. diameter steel luminaire support with a unidirectional slip base was tested in Test LS-9. This base incorporated three anchor bolt slots that were equally spaced on a $7\frac{5}{8}$-in. radius bolt circle and oriented in the same direction. The upper horizontal surface of the baseplate was sloped on a 1 to 6 slope in the area around each slot, and a matching wedge washer was used on each bolt. This arrangement allowed relief of the anchor bolt clamping force once the base began to slip. Each support was a single mast arm unit with an attached 50-lb weight to simulate the weight of a luminaire.

EXPERIMENTAL TEST RESULTS

A brief summary of the experimental data for each of the tests is given in Table 2. The behavior exhibited by each of the luminaire supports is as follows:

Test LS-1 (Figs. 1 and 2): The welds connecting the base to the pole fractured, and the entire pole was pulled from the base. The pole was completely fractured at the handhole, and the fragment from the lower end (about 18 in. long) was severely deformed. This failure mode differs from that exhibited in the NEMA pendulum test (2) of an identical support. In the pendulum test, the corners of the base were broken off, and the welds did not fail.

Test LS-2 (Figs. 3 and 4): The cast aluminum base as well as the pole itself were significantly damaged. The lower end of the pole below the handhole was broken off and dragged under the vehicle. Portions of the base remained attached to the pole segment. This mode of failure was very similar to the one in the NEMA pendulum test except that in the pendulum test the pole was not completely fractured at the handhole.

Test LS-3 (Figs. 5 and 6): The pole in this test was severely damaged although it was not completely fractured. The four corners of the base were broken off; the back two anchor bolts were bent, but the front two were not damaged. The pole scraped along the left side of the roof of the vehicle, which caused a minor deformation in the left rear area of the roof and broke the rear window. The failure modes in the vehicle crash test and NEMA pendulum test compare more closely for this support than for any other support tested.

Test LS-4 (Figs. 7 and 8): The luminaire support used in this test was identical to that used in Test LS-2, and the failure mode of the lower end of the support was very similar. However, in Test LS-4 the mast arm suffered significantly more damage than did the one in Test LS-2.

Test LS-5 (Figs. 9 and 10): No damage to the base resulted in this test. The pole was sheared adjacent to the top weld connecting it to the base. On the high-speed film, this shear failure was observed to be a progressive failure. The mast arm broke loose from the pole almost immediately, thereby reducing the mass of the portion of the luminaire support that was in contact with the vehicle. This failure mode differed significantly from that reported for the NEMA pendulum test. The pendulum test of this support resulted in a failure mode very similar to the vehicle in Test LS-3.

Test LS-6 (Figs. 11 and 12): The two pedestals on the approach side of the base failed at the manufactured "weak link" failure plane as anticipated, without causing bolt damage. Neither of the remaining two pedestals failed at the manufactured failure plane, and the anchor bolts on this side of the base were severely damaged. The base of the support contacted the right rear edge of the roof of the vehicle and slid down and along the right upper edge of the trunk compartment. This did not cause any glass breakage. No pendulum test results for a support using pedestals were available for comparison.

Figure 1. Luminaire support and vehicle after Test LS-1.

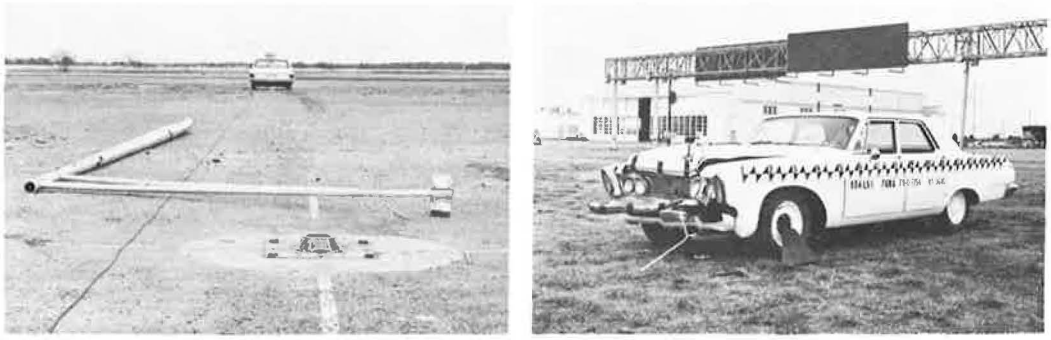


Figure 2. Final position of and damage to luminaire support, Test LS-1.

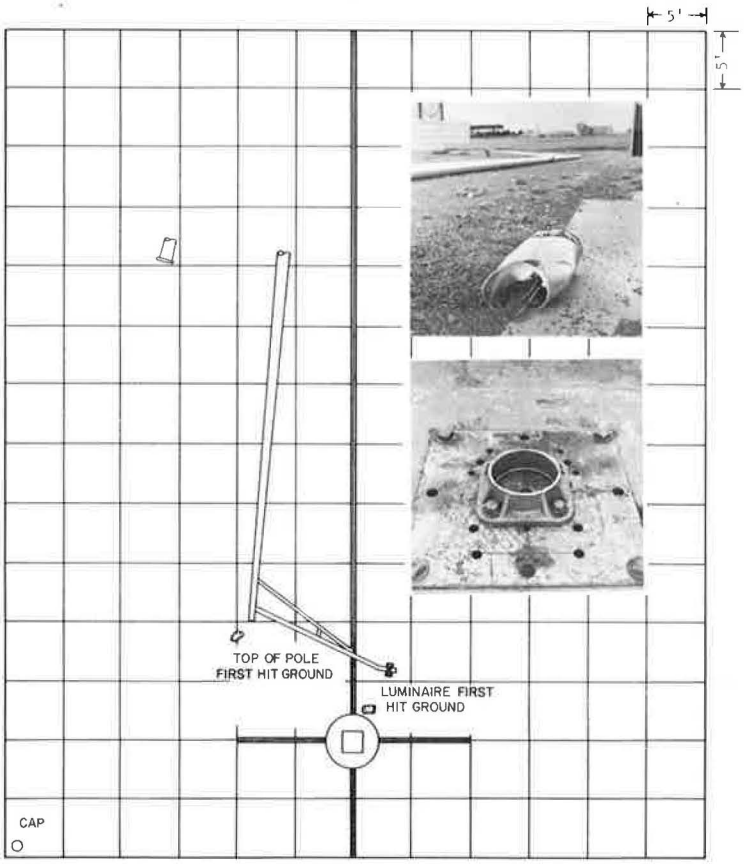


Figure 3. Luminaire support and vehicle after Test LS-2.

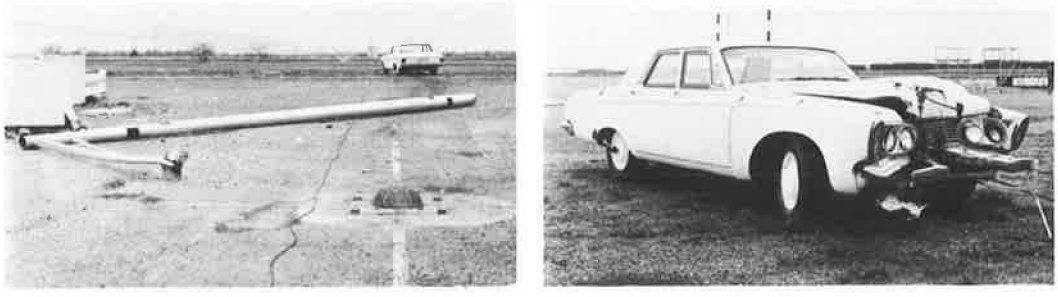


Figure 4. Final position of and damage to luminaire support, Test LS-2.

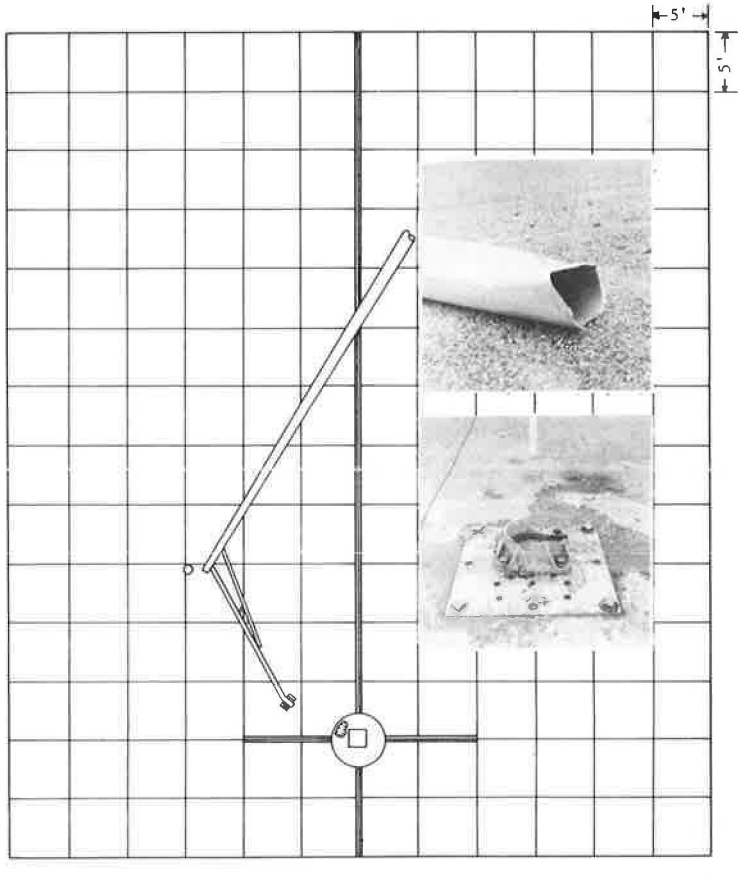


Figure 5. Luminaire support and vehicle after Test LS-3

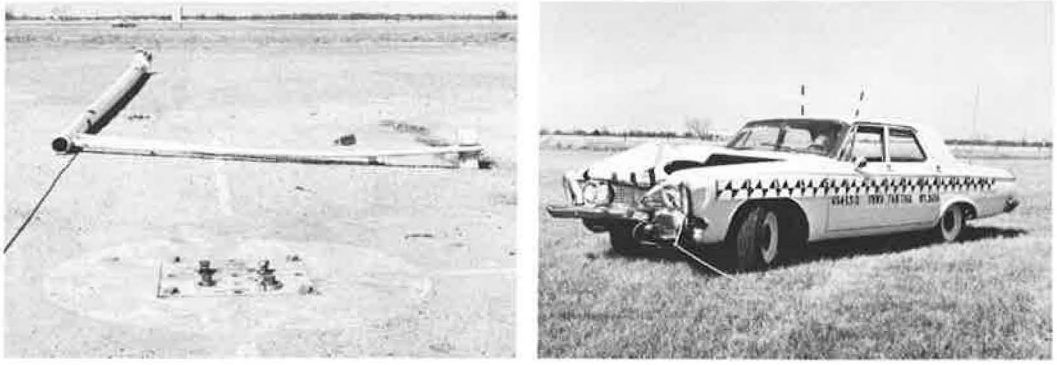


Figure 6. Final position of and damage to luminaire support, Test LS-3.

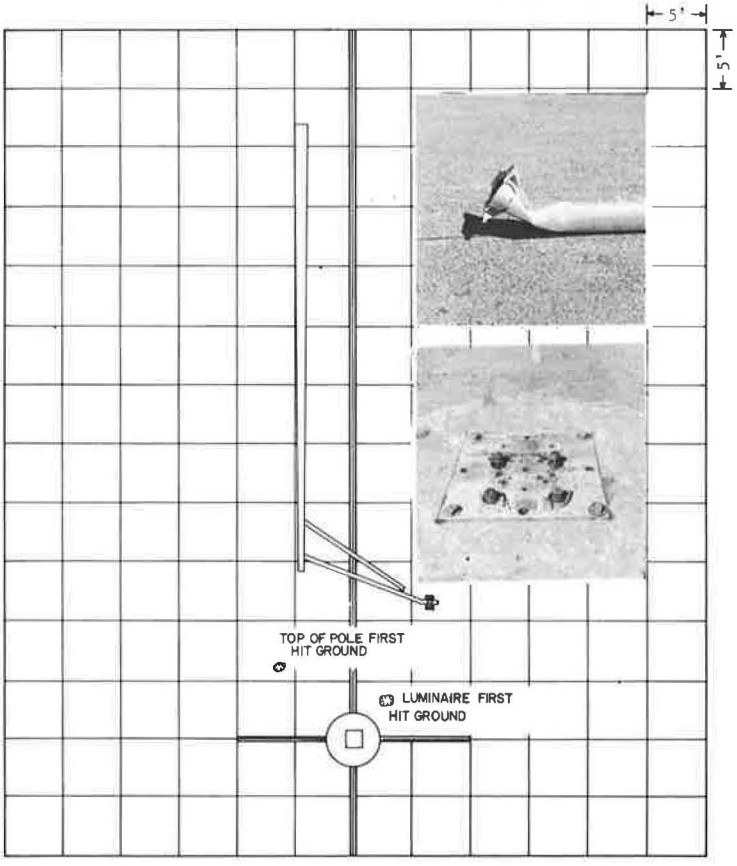


Figure 7. Luminaire support and vehicle after Test LS-4.

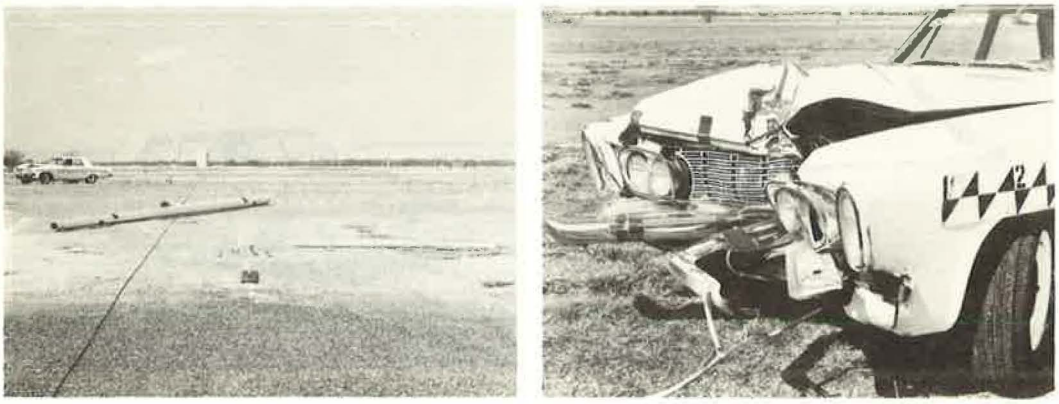


Figure 8. Final position of and damage to luminaire support, Test LS-4.

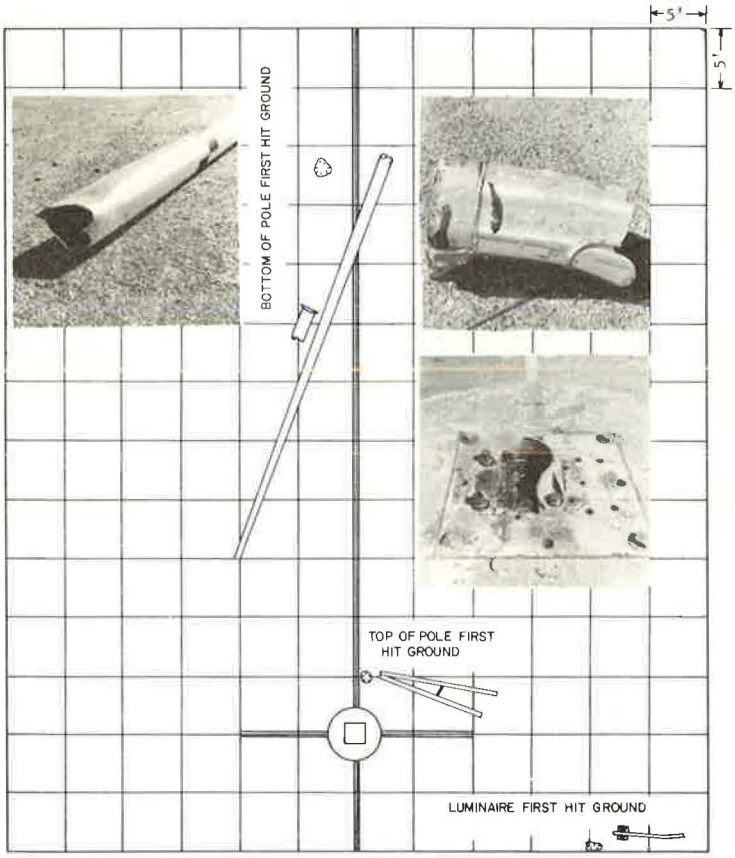


Figure 9. Luminaire support and vehicle after Test LS-5.

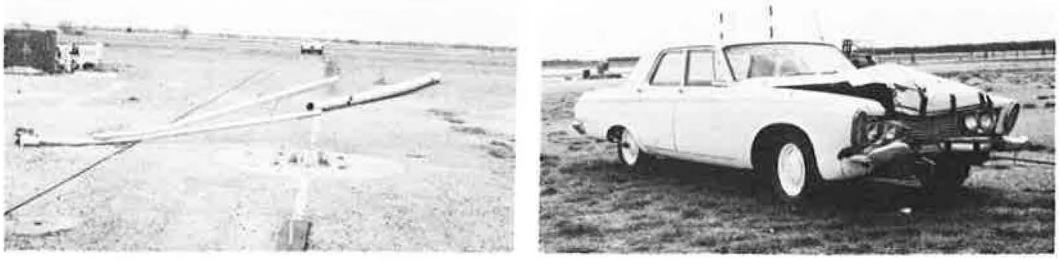


Figure 10. Final position of and damage to luminaire support, Test LS-5.

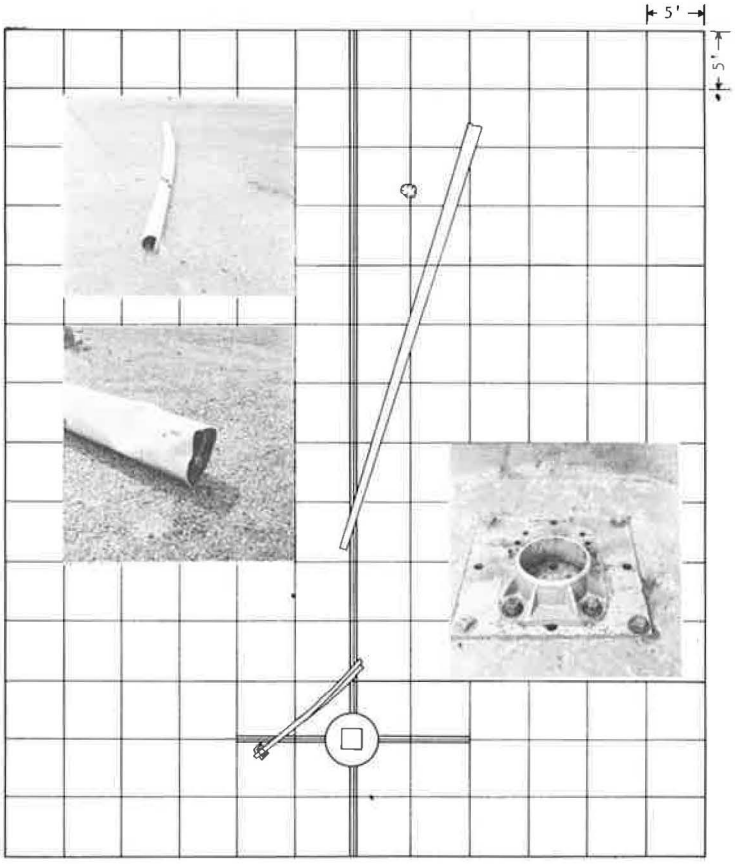
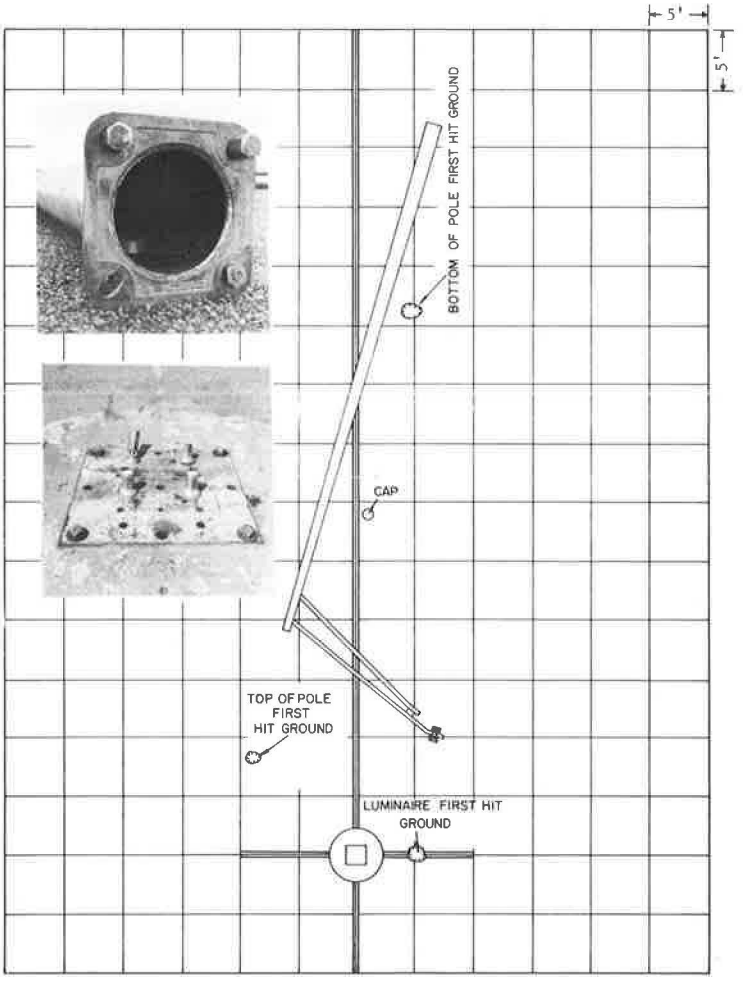


Figure 11. Luminaire support and vehicle after Test LS-6.

Figure 12. Final position of and damage to luminaire support, Test LS-6.



Test LS-7 (Figs. 13 and 14): A support identical to those used in Tests LS-2 and LS-4 was used in this test with a heavier vehicle. The failure mode exhibited here was not significantly different from the other two. A slightly larger portion of the base remained intact on the foundation and slightly more weld failure occurred.

Test LS-8 (Figs. 15 and 16): Pieces of the two front corners of the base were left in place, and a portion of the rear of the base remained on the pole. The remainder of the base was fragmented. The sides of the shoe base were forced through the space between the two rear bolts, which caused the rear bolts to bend both back and outward. The pole did not rotate and completely lose contact with the vehicle. It did reach a point at which it was only in contact with the deformed vehicle hood; then it hit the roof, cracked the front windshield, and shattered the rear window before disengaging the vehicle.

Test LS-9 (Figs. 17 and 18): The slip base on this pole became disengaged quickly, and the pole rotated up, which allowed the vehicle to pass under it with a relatively small change in speed. The slight vehicle damage and the momentum and speed change data attest to the "crashworthiness" of this support under the particular test conditions.

ANALYSIS OF TEST DATA

The values of momentum change that are given in Table 2 were calculated from high-speed film and accelerometer data. The close-up camera data were used to determine initial and final speed. Initial speed of the vehicle was calculated over a distance of about 4 ft prior to contact with the luminaire support. Final speed was calculated over a similar distance immediately after the vehicle lost contact with the luminaire support

Both the close-up and the overall views were used to estimate loss of contact. If the pole could still be seen on the close-up view at loss of contact, this view was used. Where the pole was not in view during close-up the overall view was used to determine loss of contact. By subtracting the "lost-contact" speed from the contact speed, we derived the change of speed during impact. The momentum change was found by multiplying the vehicle mass by this change in speed.

Momentum loss was also calculated by determining the speed change from the accelerometer traces. Integration of these accelerometer traces gives change in speed, which is again multiplied by vehicle mass to give change in momentum during the collision. Reasonable agreement was found between the two methods of determining change of momentum; but there is sufficient variation between the two methods that it is possible that in future testing some poles may pass a given specification by one data-analysis procedure and fail by the other. It would appear that tolerances, based on expected test variations, should be applied to the determination of specification compliance. However, the tests reported, the values obtained for momentum change using the two methods were either both below or both above the 1,100 lb-sec criterion. The maximum variation between the two momentum changes for a particular test was 125 lb-sec found in Test LS-8. The average difference in the two methods of analyzing the nine tests was 64 lb-sec, with seven of the nine showing a difference of 90 lb-sec or less.

SUMMARY OF RESULTS

A comparison of change in momentum values for the full-scale vehicle crash tests and the NEMA pendulum tests is shown in Figure 19. Change in momentum values for the Ohio, Illinois, and Maryland emergency call boxes (5) tested in an earlier phase of this study are also included in the figure. The ratio of pendulum-to-vehicle momentum changes of 400 to 1,100 lb-sec, which was implied in FHWA (TO-20), appears to be justified in four of the six tests compared, especially considering the natural variation to be expected in tests of this type. Tests LS-3 and LS-5 show the problems inherent in a specification that allows more than one test method. Test LS-3 was outside the FHWA criterion for both vehicle and pendulum tests as contrasted with Test LS-5, which was well below the criterion for vehicle tests and above the criterion for pendulum tests. Test LS-4 also was within the FHWA criterion for vehicle tests and outside it for pendulum tests.

Figure 13. Luminaire support and vehicle after Test LS-7.

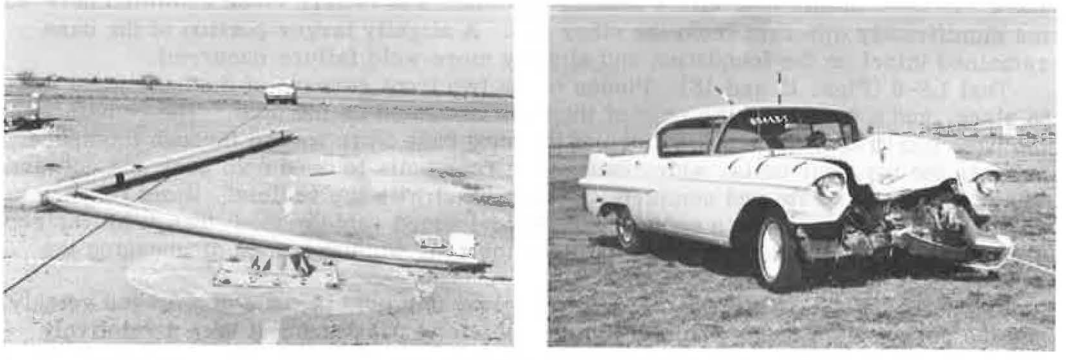


Figure 14. Final position of and damage to luminaire support, Test LS-7.

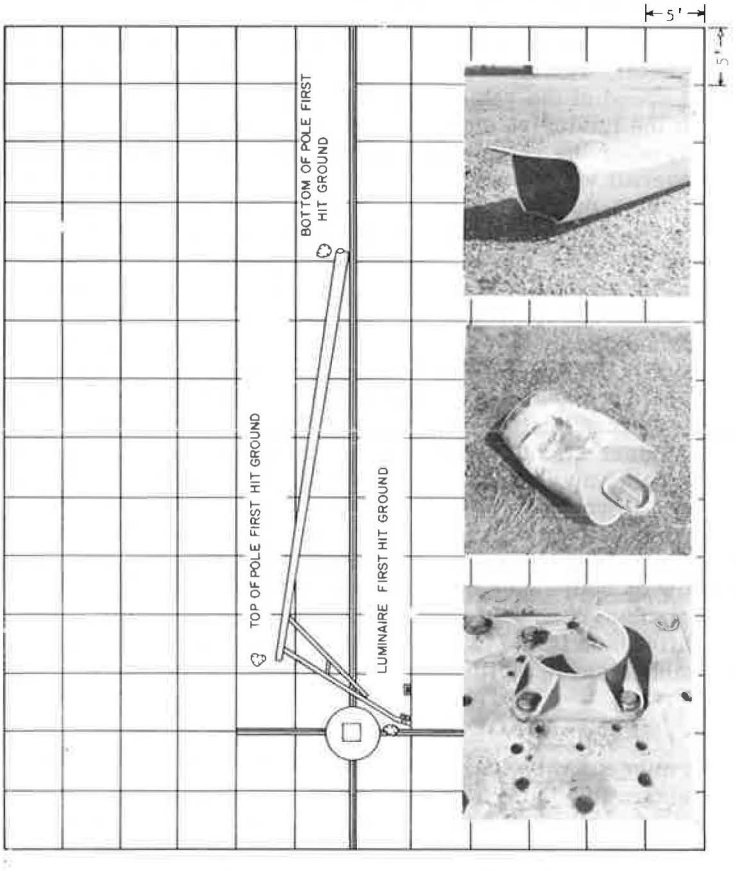


Figure 15. Luminaire support and vehicle test after Test LS-8.

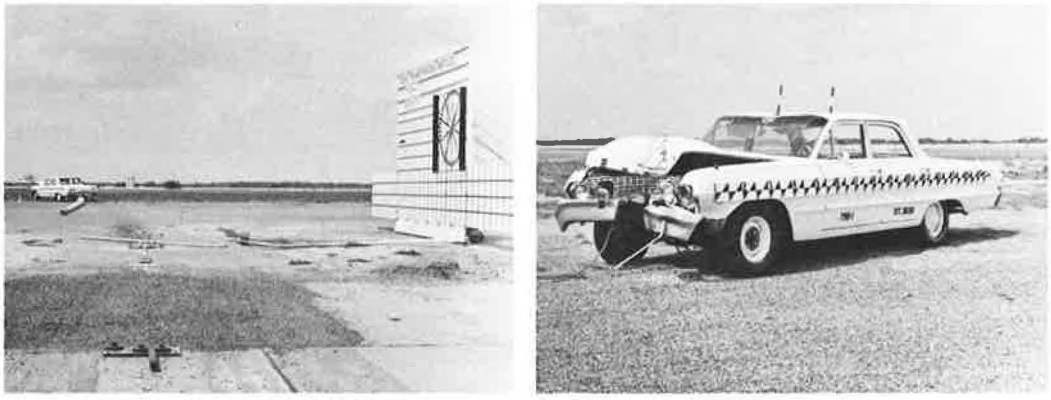


Figure 16. Final position of and damage to luminaire support, Test LS-8.

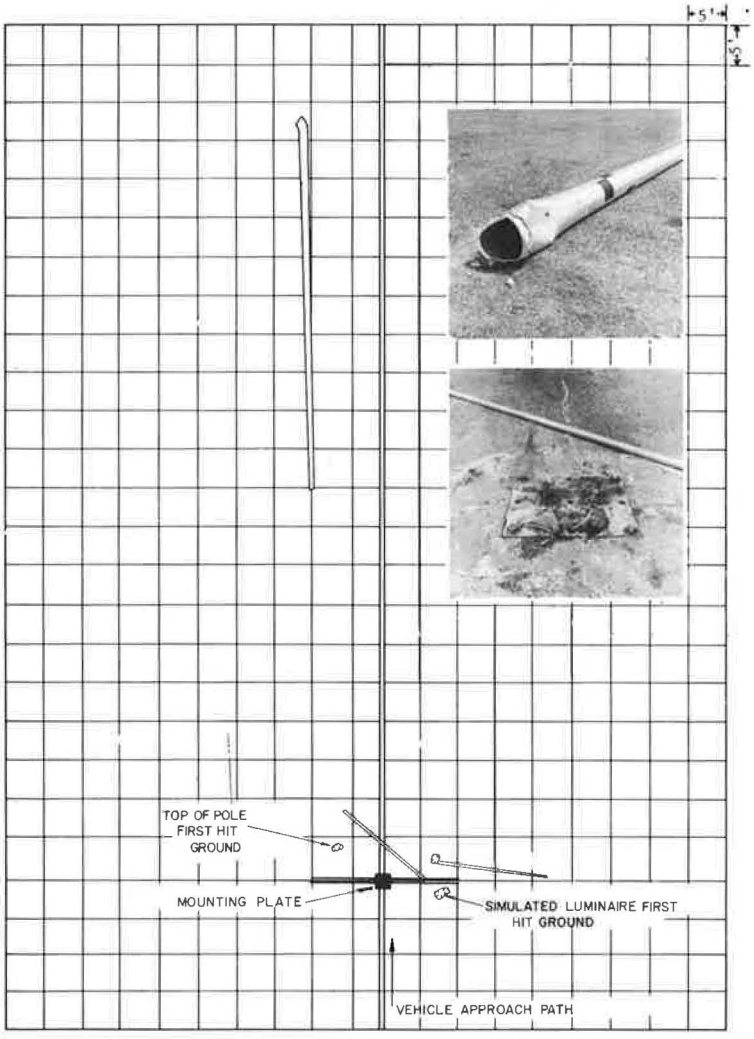


Figure 17. Luminaire support and vehicle after Test LS-9.

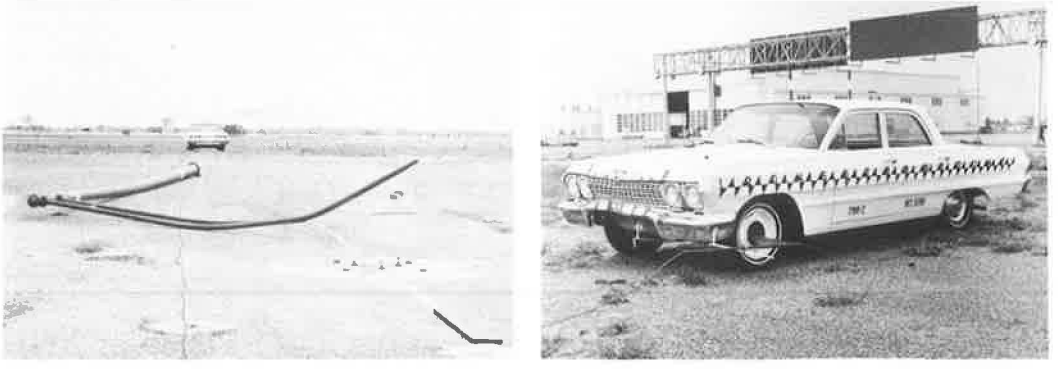


Figure 18. Final position of and damage to luminaire support, Test LS-9.

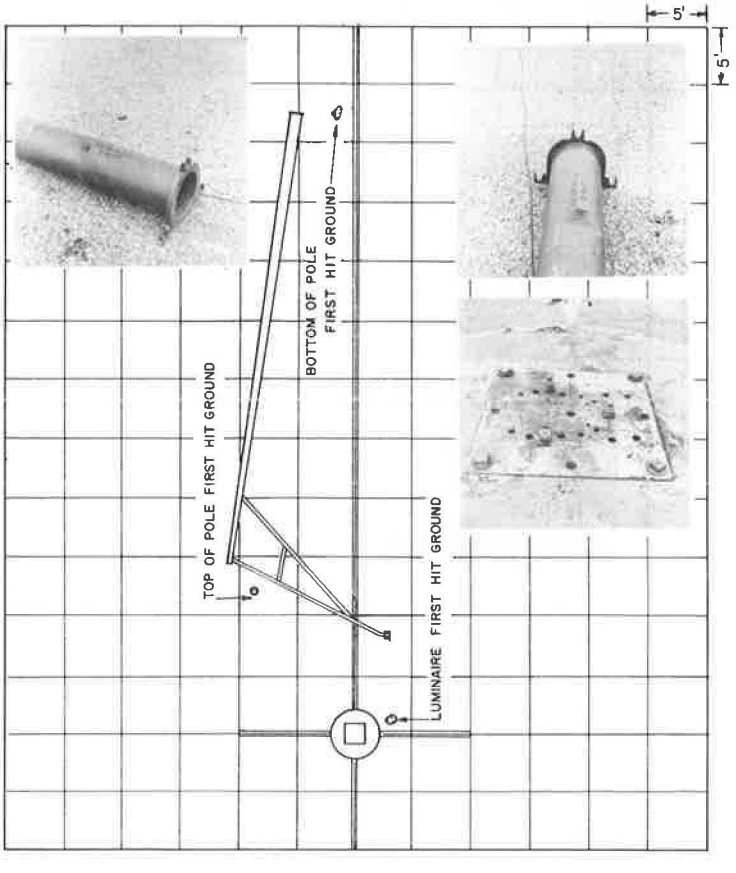
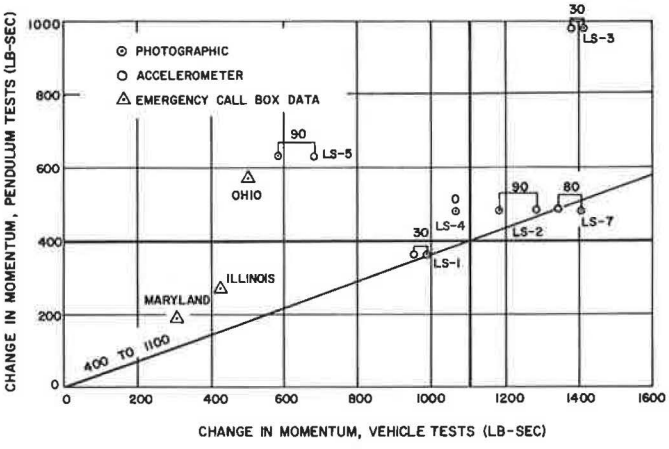


Figure 19. Comparison of momentum change in pendulum tests and full-scale vehicle tests.



In an effort to give a gross indication of test-to-test variability, we conducted Tests LS-2, LS-4, and LS-7. The vehicles used in Tests LS-2 and LS-4 were the same make and model and resulted in differences in momentum changes of 120 lb-sec when using the photographic data reduction method and 210 lb-sec when using the accelerometer method. The impact speeds of these two tests differed by 2.4 mph. The significance of this variation in speed is unknown. Test LS-7 was conducted on the same luminaire support design, but a different make and model vehicle was used. The maximum difference (340 lb-sec), using the photographic data-reduction method, was between Tests LS-4 and LS-7. It is likely that this is a significant variation considering the magnitude of variations between tests of the same make vehicle. However, several replications would be necessary to make this a definite conclusion.

Because duplicate tests were not performed in the NEMA study by Hart (2), test-to-test variations under pendulum test conditions were not indicated. Because of the scatter of data, a definitive relationship between the results of the two tests does not appear probable. Different energy levels and velocities of the impacting mass would be expected to present the possibility of different failure modes and different values of change in momentum. Different failure modes between pendulum and vehicle tests were rather pronounced for the support used in Test LS-5. Probably the most influential complicating factor is the difference in crushability of contemporary vehicles and the pendulums in current use.

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