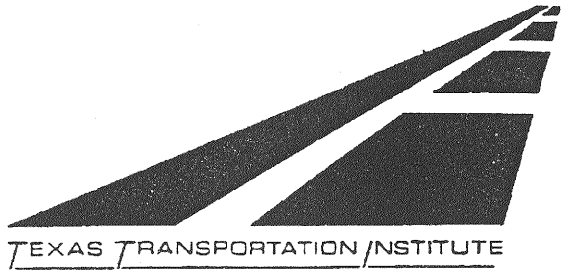


TEST AND EVALUATION OF ARIZONA SLIP-AWAY BASE LUMINAIRE SUPPORTS

TTI Report No. 472360-1F
ADOT Project No. HPR-PL-1(43)386
Contract No. 93-66

Prepared for
Arizona Transportation Research Center
Arizona Department of Transportation

Prepared by

Roger P. Bligh, P.E.
Assistant Research Engineer

Hayes E. Ross, Jr., Ph.D., P.E.
Research Engineer

and

D. Lance Bullard, Jr.
Engineering Research Associate

Texas Transportation Institute
Texas A&M University System
College Station, Tx 77843

November 1994

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/AZ-94/386		

4. Title and Subtitle	5. Report Date
TEST AND EVALUATION OF ARIZONA SLIP-AWAY BASE LUMINAIRE SUPPORTS	November 1994
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Roger P. Bligh, H. E. Ross, Jr., and D. L. Bullard, Jr.	Research Report 7236-1F
9. Performing Organization Name and Address	10. Work Unit No.
Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135	11. Contract or Grant No. HPR-PL-1(43)386
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Arizona Department of Transportation 206 S. 17th Avenue Phoenix, Arizona 85007	Final: November 1993 to September 1994
	14. Sponsoring Agency Code

15. Supplementary Notes

Prepared in cooperation with the U.S. Department of Transportation, Federal Highway Administration

16. Abstract

A study was undertaken to evaluate the impact performance of ADOT's slip-away base luminaire supports. For purposes of this evaluation, three full-scale crash tests were conducted in accordance with the requirements of *NCHRP Report 350*. During this test program, ADOT's 13.7-m (45-ft) constant tapered luminaire support was found to exhibit unacceptable impact performance. Although the slip base activated readily and the occupant impact velocity was within recommended limits, a secondary impact of the pole with the roof of the vehicle resulted in substantial deformation of the roof structure. A subsequent test of ADOT's standard 12.2-m (40-ft) luminaire system was judged to be marginally acceptable. Although the luminaire support readily yielded to the vehicle and the occupant risk criteria were well within the recommended limits established by *NCHRP Report 350*, the test vehicle once again sustained substantial deformation to the roof structure from a secondary impact with the luminaire pole. However, the magnitude and localized extent of the crush was judged to be within acceptable limits based on results of other approved systems.

Several candidate systems were identified which provide a mounting height of 13.7 m (45 ft) or greater and which could serve as replacements for ADOT's deficient 13.7-m (45-ft) poles. The most promising of these is a steel 4-bolt slip-base design developed by the Utah Department of Transportation (UDOT) which has a mounting height of 15.8 m (52 ft) and was successfully crash tested. As an alternative to adopting a new design, it is also recommended that the current design requirements be carefully reviewed and options for reducing the weight of the existing system be considered.

Maintenance practices related to slip-bolt torque were also reviewed. Although no specific post-installation inspection procedure for slip-base bolt torques is offered at this time, periodic visual inspections of slip-base poles should be considered to determine if debris, soil, corrosion, erosion, or other hindrances that could compromise proper actuation of the slip-base are present. It was also noted that although proper performance of slip-base supports depends on the clamping force in the slip-base bolts, crash tests and analytical studies indicate that the performance is not overly sensitive to the clamping force.

17. Key Words	18. Distribution Statement	23. Registrant's Seal
luminaire support, slip base, bolt torque crash test, highway safety	No restrictions. This document is available to the public through the National Technical Information Service 5285 Port Royal Road Springfield, Virginia 22161	Registered Professional Engineer (Structural) CERTIFICATE NO. 24903 HAYES E. ROSS, JR. Date Signed 12/12/94 ARIZONA, U.S.A.

19. Security Classification	20. Security Classification	21. No. of Pages	22. Price
Unclassified	Unclassified		

TABLE OF CONTENTS

LIST OF FIGURES iii

LIST OF TABLES iv

INTRODUCTION 1

RESEARCH APPROACH 2

CRASH TEST PROCEDURES 5
- Electronic Instrumentation and Data Processing 5
- Photographic Instrumentation and Data Processing 7
- Test Vehicle Propulsion and Guidance 7

CRASH TEST RESULTS 8
- 13.7-m (45-ft) Luminaire Support System 8
  - Test 472360-1 (High-Speed Test) 13
  - Test 472360-2 (Low-Speed Test) 21
- 12.2-m (40-ft) Luminaire Support System 45
  - Test 472360-3 (Low-Speed Test) 45
- Discussion 57

ACCEPTABLE SLIP-BASE LUMINAIRE SYSTEMS 65

SLIP-BASE BOLT TORQUES 70
- Background 70
- Recommended Torque Values 71
- Pole Installation and Maintenance 72
- Summary 73

CONCLUSIONS AND RECOMMENDATIONS 74

REFERENCES 76

APPENDIX A 77

APPENDIX B 80

APPENDIX C 83

APPENDIX D 86

LIST OF FIGURES

Page

Figure 1. Luminaire support and mast arm elevation 9
Figure 2. Plan view of slip-plate base 10
Figure 3. Concrete footing and reinforcing detail 11
Figure 4. 13.7-m (45-ft) Arizona slip-away base luminaire support 12
Figure 5. Vehicle prior to test 472360-1 14
Figure 6. Vehicle/test installation geometrics for test 472360-1 15
Figure 7. Vehicle properties for test 472360-1 16
Figure 8. Sequential photographs for test 472360-1. 17
Figure 9. Slip-away base luminaire support installation after test 472360-1. 19
Figure 10. Damage to slip-base (test 472360-1) 20
Figure 11. Vehicle after test 472360-1 22
Figure 12. Damage to undercarriage of vehicle (test 472360-1) 23
Figure 13. Summary of results for test 472360-1. 24
Figure 14. Vehicle angular displacements during test 472360-1 25
Figure 15. Vehicle longitudinal accelerometer trace for test 472360-1 26
Figure 16. Vehicle lateral accelerometer trace for test 472360-1 27
Figure 17. Vehicle vertical accelerometer trace for test 472360-1 28
Figure 18. Vehicle prior to test 472360-2 30
Figure 19. Vehicle/test installation geometrics for test 472360-2 31
Figure 20. Vehicle properties for test 472360-2 32
Figure 21. Sequential photographs for test 472360-2. 33
Figure 22. Slip-away base luminaire support installation after test 472360-2. 36
Figure 23. Vehicle after test 472360-2 37
Figure 24. Summary of results for test 472360-2. 39
Figure 25. Vehicle angular displacements during test 472360-2 40
Figure 26. Vehicle longitudinal accelerometer trace for test 472360-2 41
Figure 27. Vehicle lateral accelerometer trace for test 472360-2 42
Figure 28. Vehicle vertical accelerometer trace for test 472360-2 43

LIST OF FIGURES (continued)

Page

Figure 29. 12.2-m (40-ft) Arizona slip-away base luminaire support 46
Figure 30. Vehicle prior to test 472360-3 47
Figure 31. Vehicle/test installation geometrics for test 472360-3 49
Figure 32. Vehicle properties for test 472360-3 50
Figure 33. Sequential photographs for test 472360-3. 51
Figure 34. Slip-away base luminaire support installation after test 472360-3. 53
Figure 35. Vehicle after test 472360-3 54
Figure 36. Damage sustained to roof of vehicle (test 472360-3). 55
Figure 37. Summary of results for test 472360-3. 58
Figure 38. Vehicle angular displacements during test 472360-3 59
Figure 39. Vehicle longitudinal accelerometer trace for test 472360-3 60
Figure 40. Vehicle lateral accelerometer trace for test 472360-3 61
Figure 41. Vehicle vertical accelerometer trace for test 472360-3 62

LIST OF TABLES

Page

Table 1. Estimated Weight of ADOT Luminaire Pole/Slip Base Combinations 2
Table 2. Summary of NCHRP Report 350 evaluation criteria for test 472360-1 29
Table 3. Summary of NCHRP Report 350 evaluation criteria for test 472360-2 44
Table 4. Summary of NCHRP Report 350 evaluation criteria for test 472360-3 63
Table 5. Approved Luminaire Systems with Mounting Heights Greater Than 13.7 m (45-ft) 67

INTRODUCTION

Roadside safety appurtenances continue to evolve in response to advancements in technology and materials. As significant improvements in impact performance are attained, state highway agencies are compelled to periodically reevaluate their standards and make changes when appropriate. Toward this goal, the Arizona Department of Transportation (ADOT) recently conducted a review of their standard highway safety appurtenances (1). As a result of this review, several standard ADOT appurtenances were recommended for further evaluation through full-scale testing to verify their conformance with current impact performance guidelines. Included in this list of appurtenances were ADOT's standard luminaire pole and slip-away base combinations.

Although some of the lighter slip base/pole combinations appear to be acceptable based on previous crash tests of similar designs (2), there was some concern regarding the impact performance of some of the taller, heavier poles. Furthermore, the ADOT triangular slip-base design does differ slightly from those previously tested in terms of slip base bolt size, bolt circle, and bolt torque. Slip-base designs can be sensitive to such design details and the effects of these changes on safety performance is difficult to ascertain except through full-scale crash testing.

Thus, one of the primary objectives of this study was to verify the crash worthiness of ADOT's slip-away bases (ADOT standard drawings T.S. 5-2 and 5-3) for use with ADOT's standard 9.1-m (30-ft), 12.2-m (40-ft), and 13.7-m (45-ft) luminaire poles (ADOT standard drawings T.S. 4-4, 4-7, 4-8, and 4-9). In addition, maintenance practices related to slip-bolt torque were reviewed.

RESEARCH APPROACH

ADOT's lighting pole standards, as contained in the 1985 ADOT Traffic Signals and Lighting Standard Drawings, include 9.1-m (30-ft) poles (detailed in standard ADOT drawing T.S. 4-4 and 4-7), 12.2-m (40-ft) poles (T.S. 4-8), and 13.7-m (45-ft) poles (T.S. 4-9). For each of these heights there are at least two alternate designs: a step tapered option which consists of three different sizes of pipe connected with specially fabricated reducing sections, and a constant taper option which has a uniform thickness and a specified taper rate. These poles are mounted on one of two slip-base designs. The 9.1-m (30-ft) poles are mounted on a slip-away base detailed in standard drawing T.S. 5-2. The 12.2 (40) and 13.7-m (45-ft) poles are used in combination with the base detailed in T.S. 5-3.

An assessment of ADOT's luminaire pole/slip base combinations was conducted to identify which systems are likely to be most critical in terms of impact performance. For a given slip-base design, the impact performance is known to be sensitive to the total mass of the luminaire system. The estimated weight of ADOT's standard luminaire pole/slip base combinations is shown in Table 1. The weights presented in this table are representative of the total weight of the installation including pole, pole base plate, mast arm, and luminaire.

Table 1. Estimated Weight of ADOT Luminaire Pole/Slip Base Combinations.

Standard Drawing #	Pole Type	Pole Length m (ft)	Weight[a] kg (lb)	
			Constant Taper	Step Taper
T.S. 4-4	D	9.1 (30)	283.5 (625)	265.3 (585)
T.S. 4-7	G	9.1 (30)	269.9 (595)	292.6 (645)
T.S. 4-8	H	12.2 (40)	385.6 (850)[b]	351.5 (775)
T.S. 4-9	J	13.7 (45)	452.2 (997)[b]	555.7 (1225)[b,c]

[a]Calculated weight includes pole, pole base plate, 6.1 m (20 ft) mast arm, and luminaire
[b]Measured weight of actual luminaire components
[c]Exceeds FHWA recommendations (4)

In a memorandum from the Federal Highway Administration (FHWA) to regional federal highway administrators dated July 16, 1990 (4), requirements pertaining to the use of steel slip-base luminaire supports on federal-aid highways were set forth. Contained within this set of requirements is a maximum weight restriction (including pole, base plate, mast arm, and luminaire) of 453.6 kg (1,000 lb). The reason for this limit is that tests of systems exceeding this weight have exhibited undesirable safety performance.

As shown in Table 1, ADOT's 13.7-m (45-ft) step-tapered pole exceeds the FHWA weight limit and it is therefore presumed that this system will display unacceptable impact performance. In light of this potential deficiency, the limited use of this system, and the availability of other systems which have similar mounting heights but less total mass, ADOT engineers agreed to eliminate the 13.7-m (45-ft) step-taper pole from ADOT standards. Testing of this system under this study was therefore not conducted.

The next most critical design in terms of total mass is the 13.7-m (45-ft) constant tapered luminaire pole. This system consists of a single tapered pole with a constant 7-gauge wall thickness. The total weight of the system with a 6.1-m (20-ft) mast arm and luminaire was measured to be 452.2 kg (997 lb) which is just under the recommended weight limit of 453.6 kg (1,000 lb) established by the FHWA memorandum (4). For this reason, the crashworthiness of this system was considered questionable and it was recommended that its impact performance be verified through full-scale testing.

The 13.7-m (45-ft) luminaire system was therefore selected for testing based on the premise that if it successfully passed the required impact criteria, that system, as well as all lighter ADOT systems supported on similar slip-base designs, would be considered crashworthy. That is, if the most critical system passes all test requirements, it is reasonable to assume that all lighter systems of similar design will also perform satisfactorily and no further testing would be necessary.

In the event that the 13.7-m (45-ft) pole was found to be deficient, the next most critical system (i.e., the 12.2-m (40-ft) constant tapered pole) would be tested. In addition, information pertaining to approved luminaire systems would be collected and alternatives suitable for replacement of the 13.7-m (45-ft) pole would be recommended.

Finally, installation and maintenance practices related to slip-bolt torque were reviewed. This was accomplished through written correspondence and telephone interviews with the Federal Highway Administration and standards and maintenance engineers of state highway agencies which currently utilize slip-base luminaire designs. The results of these efforts are summarized in the sections which follow.

CRASH TEST PROCEDURES

All crash tests were conducted and evaluated in accordance with *National Cooperative Highway Research Program (NCHRP) Report 350*, "Recommended Procedures for the Safety Performance Evaluation of Highway Features" (3), and the 1990 American Association of State Highway Transportation Officials (AASHTO) *Standards Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals* (5).

NCHRP Report 350 recommends two tests to certify the crashworthiness of breakaway support structures: a low-speed test and a high-speed test. The low-speed test, test designation 3-60, involves an 820-kg (1,800-lb) passenger car impacting the support structure at a speed of 35 km/h (21.7 mi/h). This test is intended to evaluate the breakaway mechanism of the support. The high-speed test, test designation 3-61, involves an 820-kg (1,800-lb) vehicle impacting the support structure at 100 km/h (62.1 mi/h). The primary intent of this test is to evaluate vehicle and test article trajectory. Evaluation of occupant risk criteria and test object penetration into the occupant compartment are an important concern for both tests. Brief descriptions of the crash test and data analysis procedures used in the study are presented below.

Electronic Instrumentation and Data Processing

Each test vehicle was instrumented with three solid-state angular rate transducers to measure roll, pitch and yaw rates; a triaxial accelerometer at the vehicle center-of-gravity to measure longitudinal, lateral, and vertical acceleration levels, and a back-up biaxial accelerometer in the rear of the vehicle to measure longitudinal and lateral acceleration levels. The accelerometers were strain gauge type with a linear millivolt output proportional to acceleration.

The electronic signals from the accelerometers and transducers were transmitted to a base station by means of constant bandwidth FM/FM telemetry link for recording on magnetic tape and for display on a real-time strip chart. Provision was made for the transmission of calibration signals before and after the test, and an accurate time reference signal was simultaneously recorded with the data. Pressure sensitive contact switches on the bumper were actuated just prior to impact by wooden dowels to indicate the elapsed time over a known distance to provide

a measurement of impact velocity. The initial contact also produced an "event" mark on the data record to establish the exact instant of contact with the luminaire support.

The multiplex of data channels, transmitted on one radio frequency, was received at a data acquisition station, and demultiplexed into separate tracks of Intermediate Range Instrumentation Group (I.R.I.G.) tape recorders. After the test, the data was played back from the tape machines, filtered with a SAE J211 Class 180 filter, and were digitized using a microcomputer, for analysis and evaluation of impact performance. The digitized data were then processed using two computer programs: DIGITIZE and PLOTANGLE. Brief descriptions on the functions of these two computer programs are given below.

The DIGITIZE program uses digitized data from vehicle-mounted linear accelerometers to compute occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, and the highest 10-msec average ridedown acceleration. The DIGITIZE program also calculates a vehicle impact velocity and the change in vehicle velocity at the end of a given impulse period. In addition, maximum average accelerations over 50-msec intervals in each of the three directions are computed. Acceleration versus time curves for the longitudinal, lateral, and vertical directions are then plotted from the digitized data of the vehicle-mounted linear accelerometers using a commercially available software package.

The PLOTANGLE program uses the digitized data from the yaw, pitch, and roll rate charts to compute angular displacement in deg at 0.00067-s intervals and then instructs a plotter to draw a reproducible plot of yaw, pitch, and roll versus time. It should be noted that these angular displacements are sequence dependent with the sequence being yaw-pitch-roll for the data presented herein. These displacements are in reference to the vehicle-fixed coordinate system with the initial position and orientation of the vehicle-fixed coordinate system being that which existed at initial impact.

An uninstrumented Alderson Research Laboratories Hybrid II, 50th percentile male anthropomorphic dummy, restrained with lap and shoulder belts, was placed in the driver's position of the vehicle.

Photographic Instrumentation and Data Processing

Photographic coverage of each test included two high-speed cameras. One camera was positioned to have a field of view perpendicular to and aligned with the luminaire support structure. A second camera was placed downstream of the luminaire support at an angle of approximately 45 degrees to impact. A flash bulb activated by pressure sensitive tape switches was positioned on the impacting vehicle to indicate the instant of contact with the support structure and was visible from each camera. The films from these high-speed cameras were analyzed on a computer-linked motion analyzer to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A professional video camera and a Betacam videotape recorder along with still cameras were used for documentary purposes and to record conditions of the test vehicle and test installation before and after the test.

Test Vehicle Propulsion and Guidance

The test vehicles were towed into the support structure using a steel cable guidance and reverse tow system. A steel cable for guiding the test vehicles was tensioned along the impact path, anchored at each end, and threaded through a guide plate attachment anchored to the front wheel of the test vehicle. Another steel cable was connected to the test vehicles, passed around a pulley near the impact point, through a pulley on the tow vehicle, and then anchored to the ground such that the tow vehicle moved away from the test site. A 2-to-1 speed ratio between the test and tow vehicle existed with this system. Just prior to impact with the guardrail system, the test vehicle was released to be free-wheeling and unrestrained. The vehicle remained free-wheeling, i.e., no steering or braking inputs, until the vehicle cleared the immediate area of the test site, at which time brakes on the vehicle were activated to bring the vehicle to a safe and controlled stop.

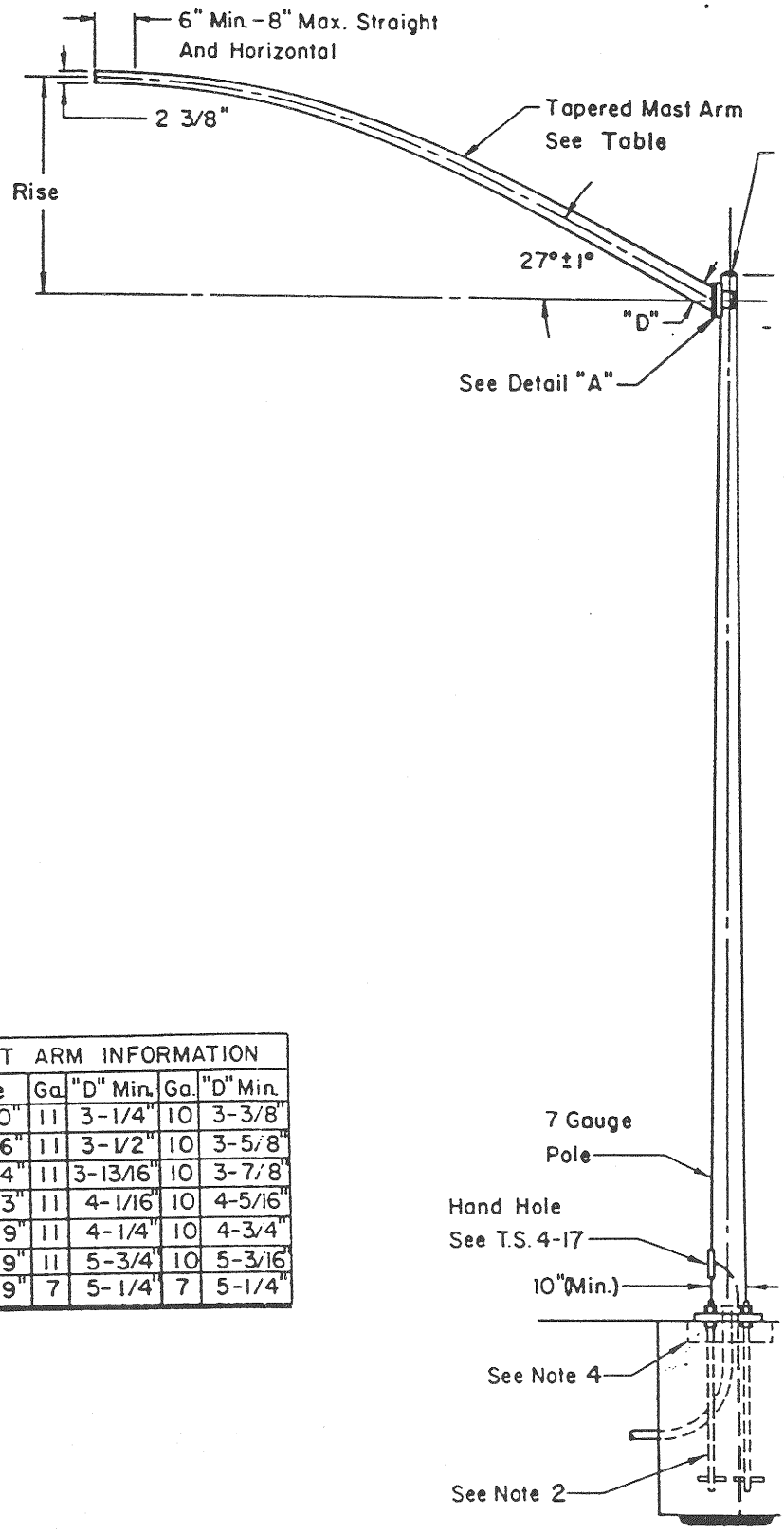
CRASH TEST RESULTS

13.7-m (45-ft) Luminaire Support System

As mentioned previously, the 13.7-m (45-ft) constant tapered luminaire pole was believed to be the most critical design in terms of impact performance and it was therefore selected for crash testing. For purposes of the full-scale crash test program, a luminaire support structure conforming to ADOT specifications was erected at the TTI Proving Ground facilities. The luminaire support, shown in Figure 1, was 13.7 m (45.0 ft) in length and was constructed from 7-ga. A595, Grade A steel. Attached to the luminaire support pole was a 6.1 m (20.0 ft) tapered mast arm also constructed from 7-ga steel. The rise of the mast arm was 1.75 m (5.75 ft) as measured from the center of the pole attachment point to the center of the end of the mast arm. Attached to the end of the mast arm was a standard luminaire supplied by ADOT. The total weight of the system, which included the pole, pole base plate, mast arm, and luminaire, was measured to be 452.2 kg (997 lb).

The base plate of the luminaire support pole, shown in Figure 2, was a three-bolt, omni-directional design with a 0.4 m (1.3 ft) diameter bolt circle. The base plates were constructed from 69.9 mm (2.8 in) thick steel plate. Placed between the foundation and support pole slip-away base plates and on both ends of the slip-plate bolts were 7.9 mm (.3 in) x 92.1 mm (3.6 in) x 57.2 mm (2.3 in) plate washers. A 28-ga keeper plate was used to aid in retaining the slip-base bolts. The slip-base bolts were torqued to 281.8 N-m (208 ft-lb) in accordance with ADOT standards.

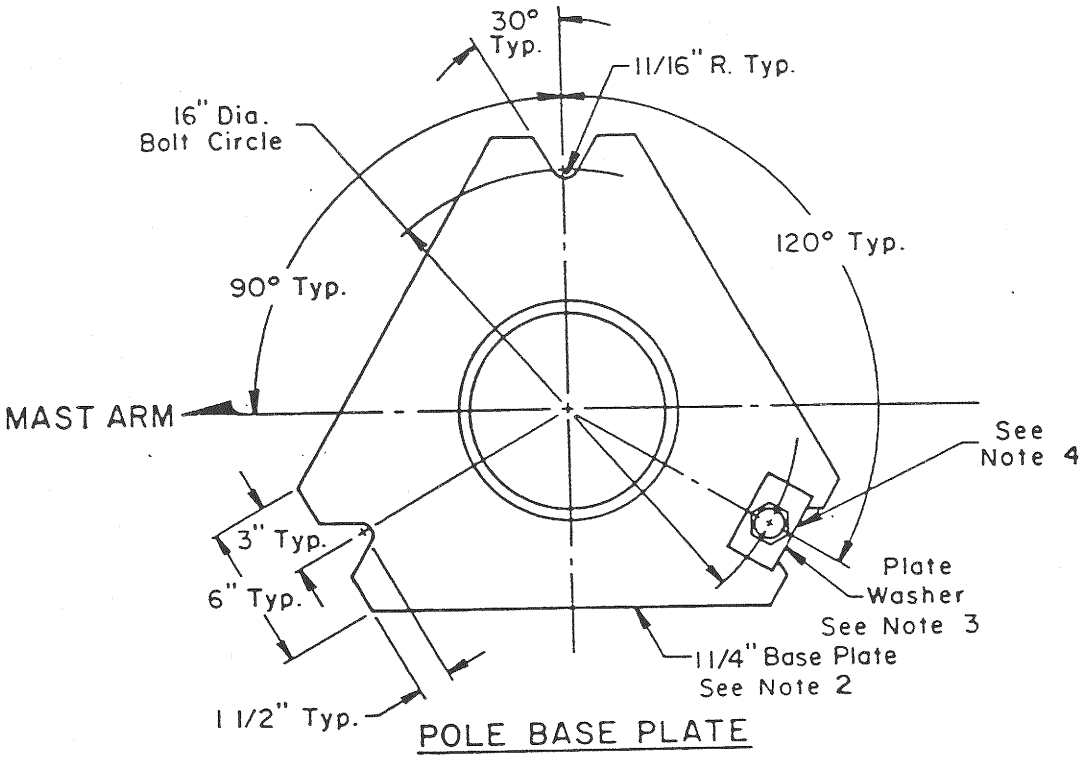
The luminaire support was attached to a standard three-bolt slip-away base anchored to a concrete footing. Details of the concrete footing are shown in Figure 3. The drilled shaft was 0.9 m (3.0 ft) in diameter and 2.4 m (8.0 ft) deep. The reinforcement consisted of eight No. 7 bars and a spiral cage fabricated from 12.7 mm (0.5 in) cold drawn steel wire spiraled with a 88.9 mm (3.5 in) pitch. Three 25.4 mm (1.0 in) diameter x 914.4 mm (36 in) long high strength steel anchor bolts were embedded into the concrete footing for attachment of the foundation base plate. All hardware, including foundation base plate, pole base plate, pole, mast arm, luminaire, anchor bolts, and other connecting bolts, nuts, and washers were supplied by ADOT. The completed test installation is shown in Figure 4.



MAST ARM INFORMATION					
Lgth.	Rise	Ga.	"D" Min.	Ga.	"D" Min.
6'	2'-0"	11	3-1/4"	10	3-3/8"
8'	2'-6"	11	3-1/2"	10	3-5/8"
10'	3'-4"	11	3-13/16"	10	3-7/8"
12'	4'-3"	11	4-1/16"	10	4-5/16"
15'	4'-9"	11	4-1/4"	10	4-3/4"
18'	5'-9"	11	5-3/4"	10	5-3/16"
20'	5'-9"	7	5-1/4"	7	5-1/4"

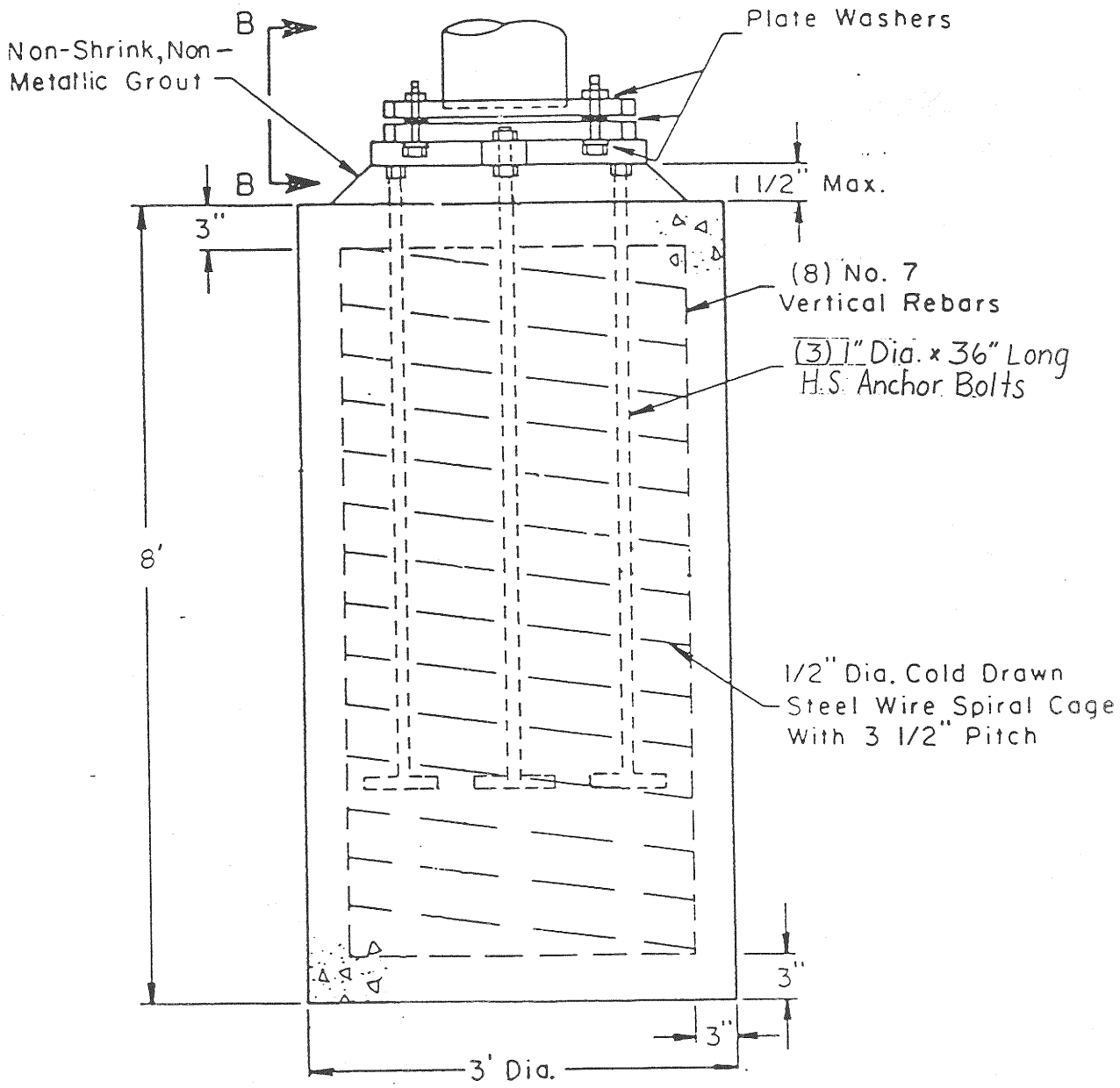
1 ft = 0.305 m
1 in = 25.4 mm

Figure 1. Luminaire support and mast arm elevation.



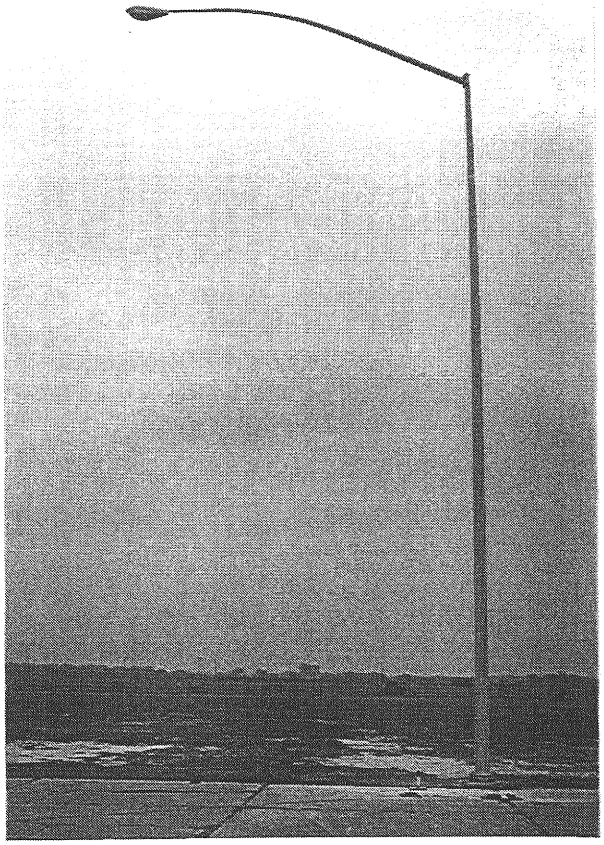
1 ft = 0.305 m 1 in = 25.4 mm

Figure 2. Plan view of slip-plate base.



1 ft = 0.305 m
1 in = 25.4 mm

Figure 3. Concrete footing and reinforcing detail.



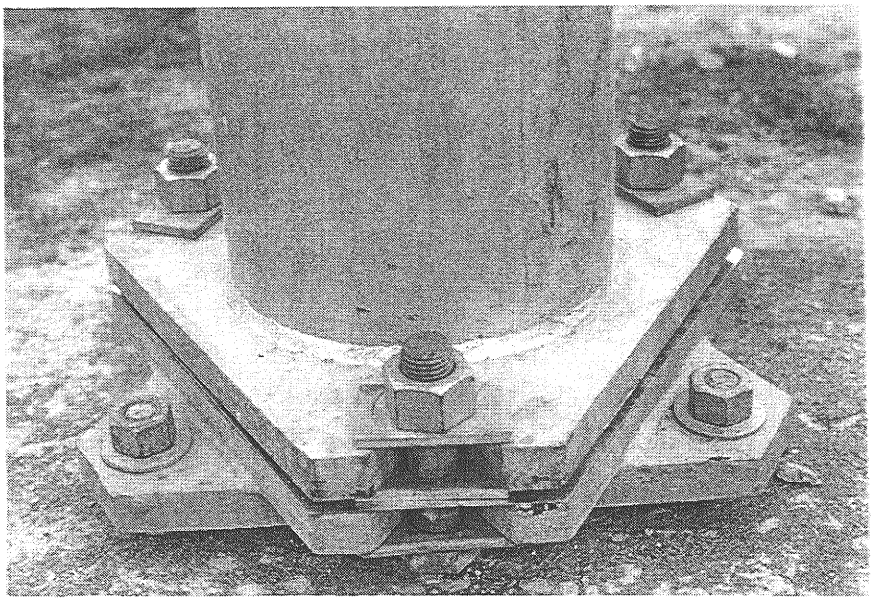


Figure 4. 13.7-m (45-ft) Arizona slip-away base luminaire support.

Test 472360-1 (High-Speed Test)

The test vehicle, shown in Figure 5, was a 1988 Subaru Justy. Test inertia weight of the vehicle was 820 kg (1,808 lb) and its gross static weight was 893 kg (1,969 lb). The height to the lower edge of the vehicle bumper was 13.5 in (34.3 cm) and the height to the top of the bumper was 21.0 in (53.3 cm). The position of the vehicle relative to the luminaire pole is shown in Figure 6. Additional dimensions and information pertaining to the test vehicle are given in Figure 7. The vehicle was directed into the guardrail system using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact.

The vehicle impacted the luminaire support, with the centerline of the vehicle aligned with the centerline of the support, at a speed of 102.2 km/h (63.5 mi/h) and a zero degree heading angle. Upon impact, the slip base activated as designed and the vehicle imparted an angular and translational velocity to the pole. As the vehicle passed over the foundation base plate, the cross-member under the vehicle's engine contacted the front anchor bolt. This contact caused some undercarriage damage to the vehicle and resulted in the nut being spun off the anchor bolt. As the pole rotated, lifting the base into the air, the pole base plate momentarily snagged on the front of the vehicle. This snagging caused the front of the vehicle to briefly unload prior to loss of contact with the support. The vehicle then traveled under the rotating pole without further incident. After the vehicle lost contact with the test article, the brakes were applied and the vehicle came to rest at a point 109.8 m (360.0 ft) downstream and 11.0 m (36.0 ft) left of the point of impact.

The installation, still airborne, continued to rotate until the end of the mast arm contacted the ground approximately 0.8 s after impact. Shortly thereafter, with the base of the support still airborne, the top-end of the support bounced off the ground surface. After rebounding into the air one more time when the base of the pole struck the ground, the support finally came to rest approximately 2.7 s after impact. Sequential photographs of the impact are shown in Figure 8.

As shown in Figure 9, the luminaire support sustained considerable damage. Both the support pole and mast arm were bent and would require replacement, as would the luminaire which became detached from the mast arm and shattered on the ground surface. As shown in Figure 10, damage to the foundation base plate caused from contact with the vehicle's undercarriage was relatively minor and would not necessitate repair.

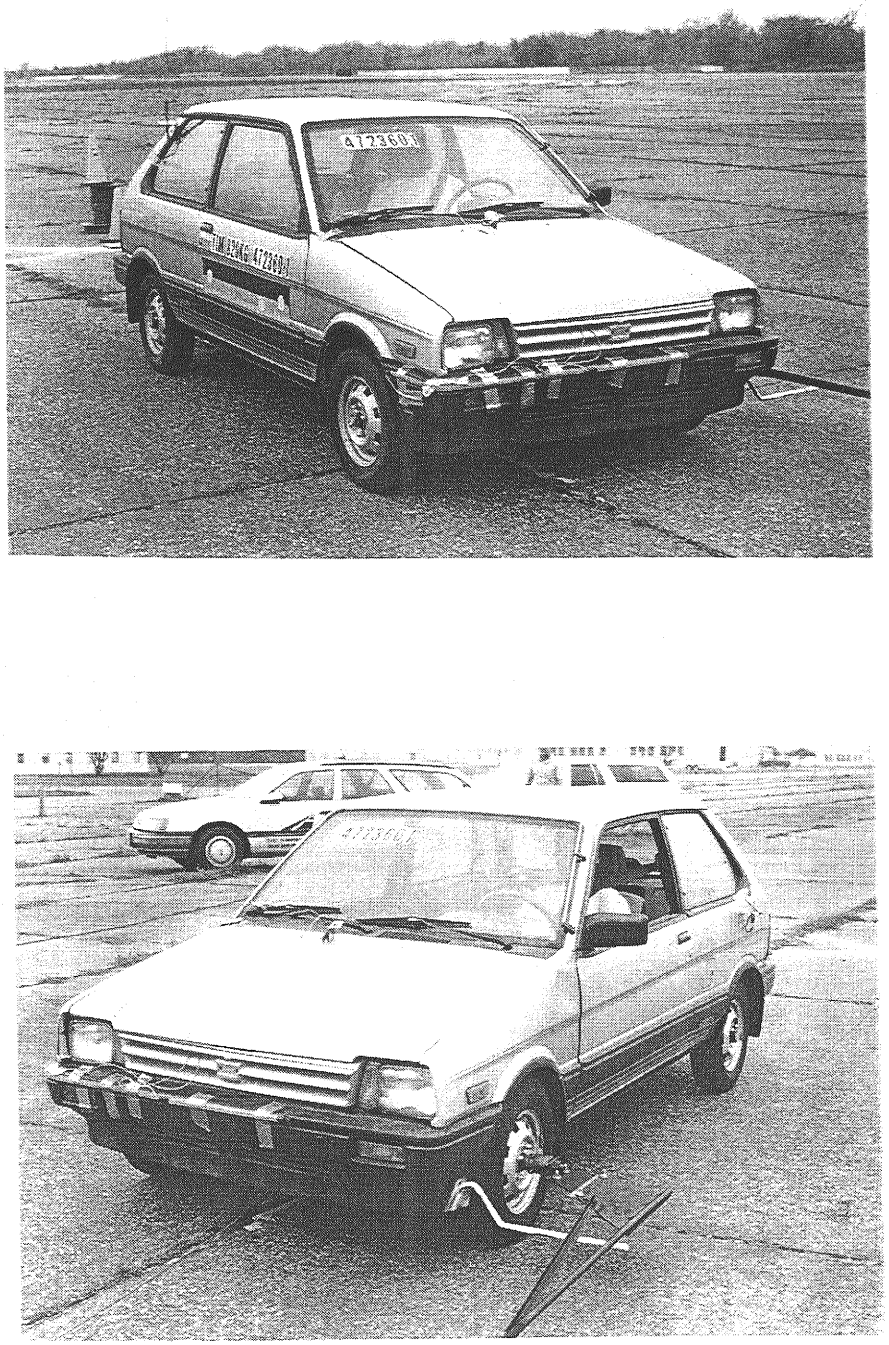


Figure 5. Vehicle prior to test 472360-1.

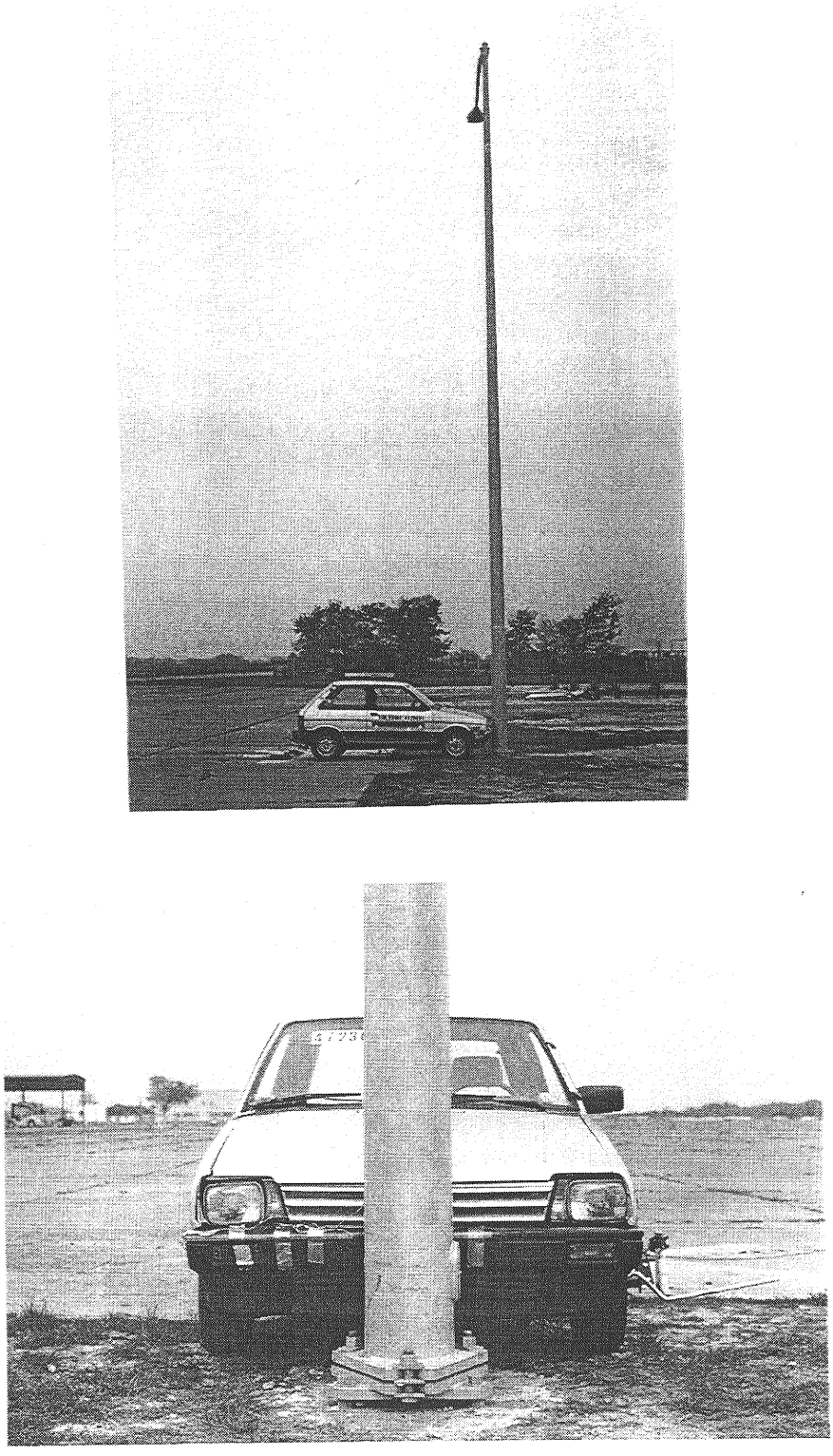


Figure 6. Vehicle/test installation geometrics for test 472360-1.

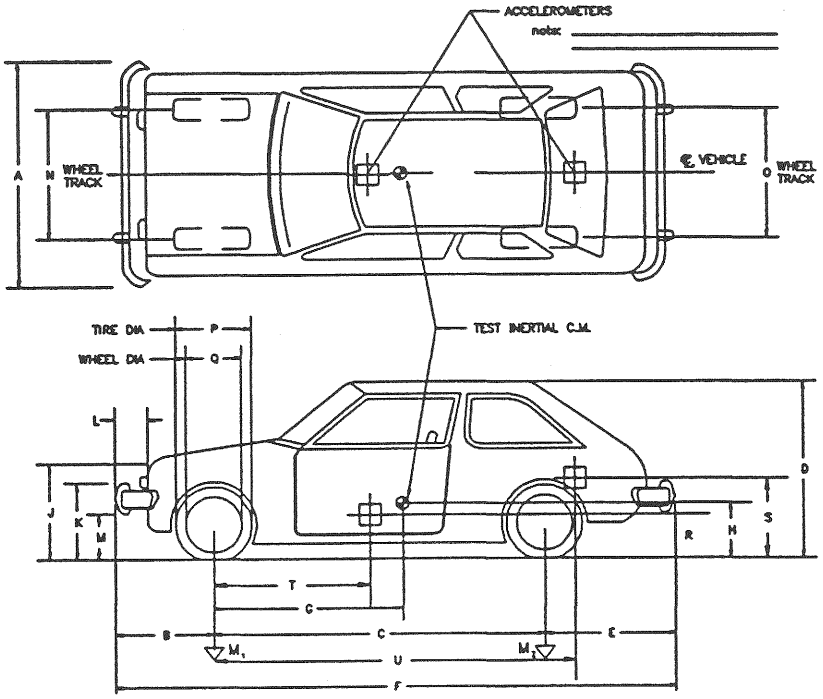
DATE: 3-24-94 TEST NO.: 472360-1 VIN NO.: JFiKA73ADJB7D9994 MAKE: Subaru

MODEL: Justy GL YEAR: 1988 ODOMETER: 47874 TIRE SIZE: 155 R12

TIRE INFLATION PRESSURE: _____

MASS DISTRIBUTION (kg) LF 254 RF 254 LR 158 RR 154

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



ENGINE TYPE: 3 cyl Gas

ENGINE CID: 73

TRANSMISSION TYPE:

X AUTO

_ MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: _____

MASS: _____

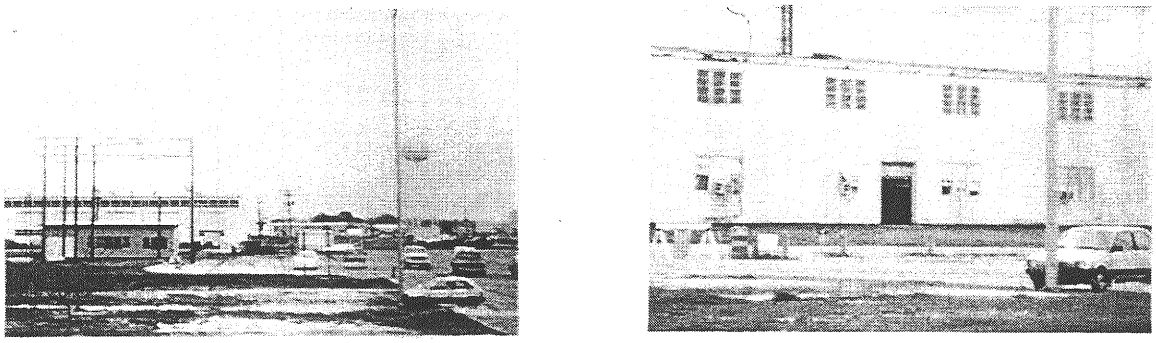
SEAT POSITION: _____

GEOMETRY – (mm)

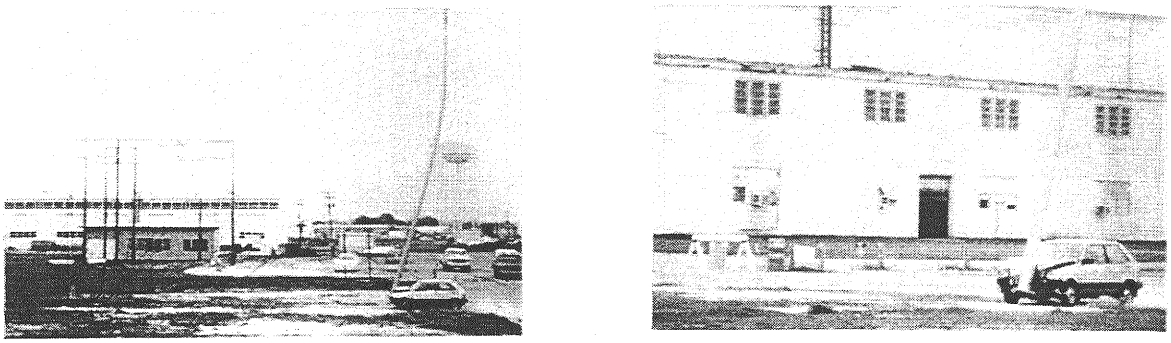
A 1510	E 600	J 730	N 1340	R 430
B 590	F 3450	K 525	O 1290	S 760
C 2260	G 860	L 75	P 540	T 870
D 1370	H _____	M 370	Q 334	U 2600

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	500	508	547
M_2	273	312	346
M_T	773	820	893

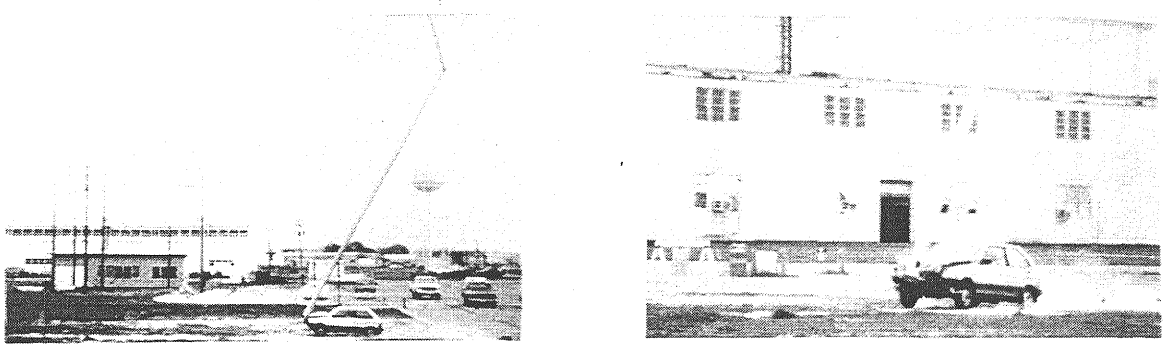
Figure 7. Vehicle properties for test 472360-1.



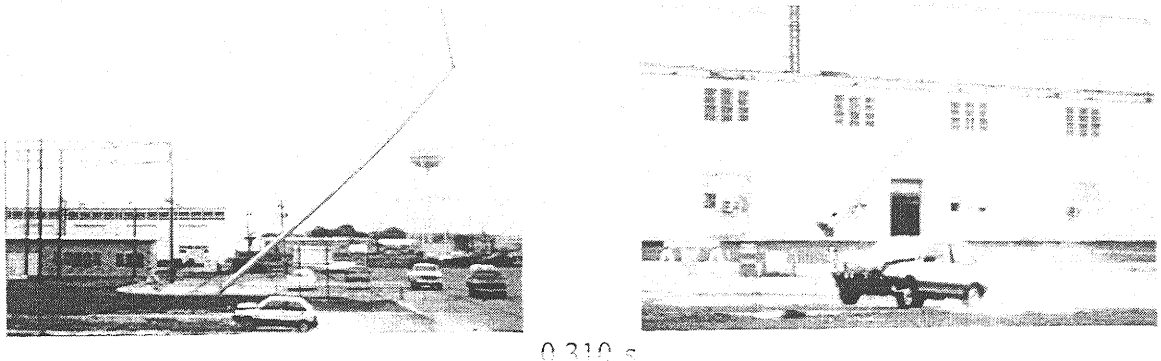
0.000 s



0.103 s



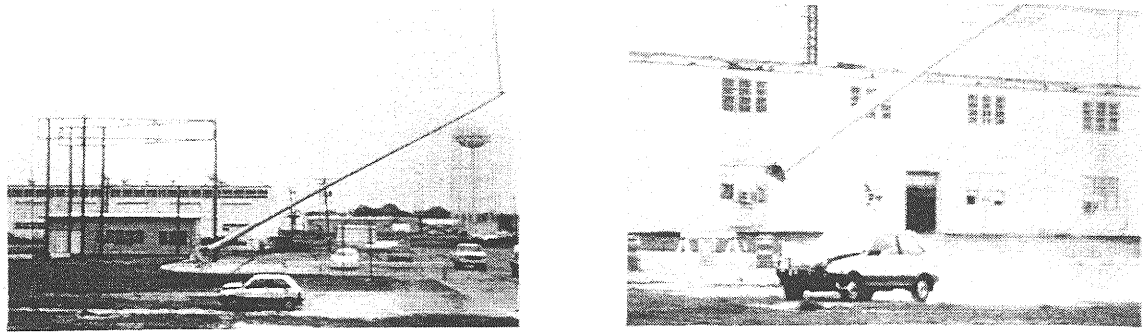
0.206 s



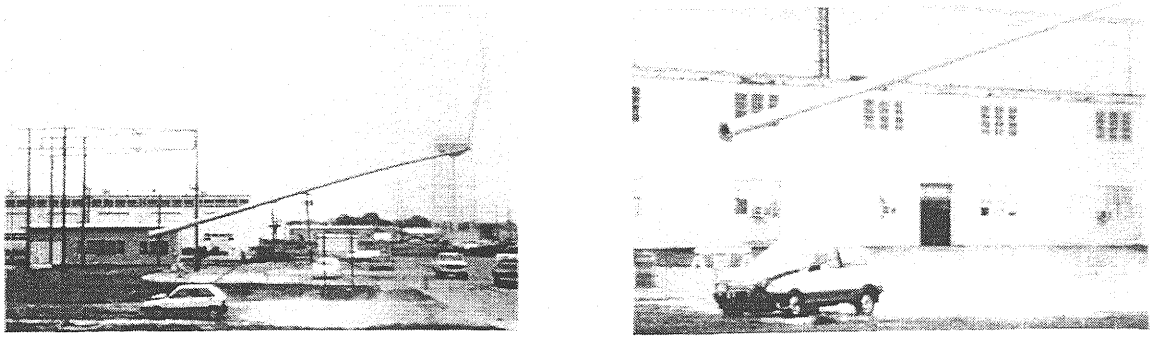
0.310 s

Figure 8. Sequential photographs for test 472360-1.

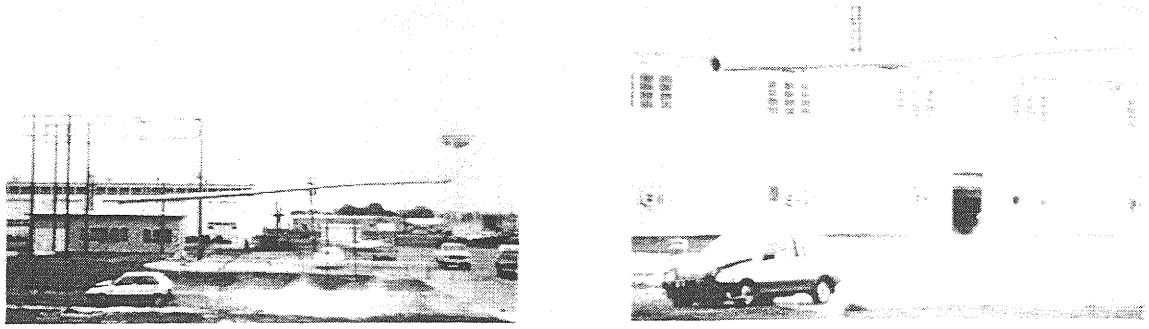
(perpendicular and downstream angular views)



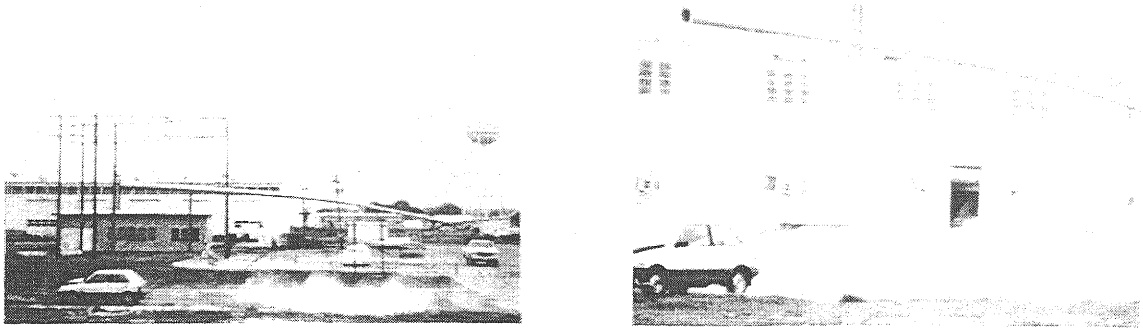
0.413 s



0.516 s



0.619 s



0.723 s

Figure 8. Sequential photographs for test 472360-1 continued.

(perpendicular and downstream angular views)

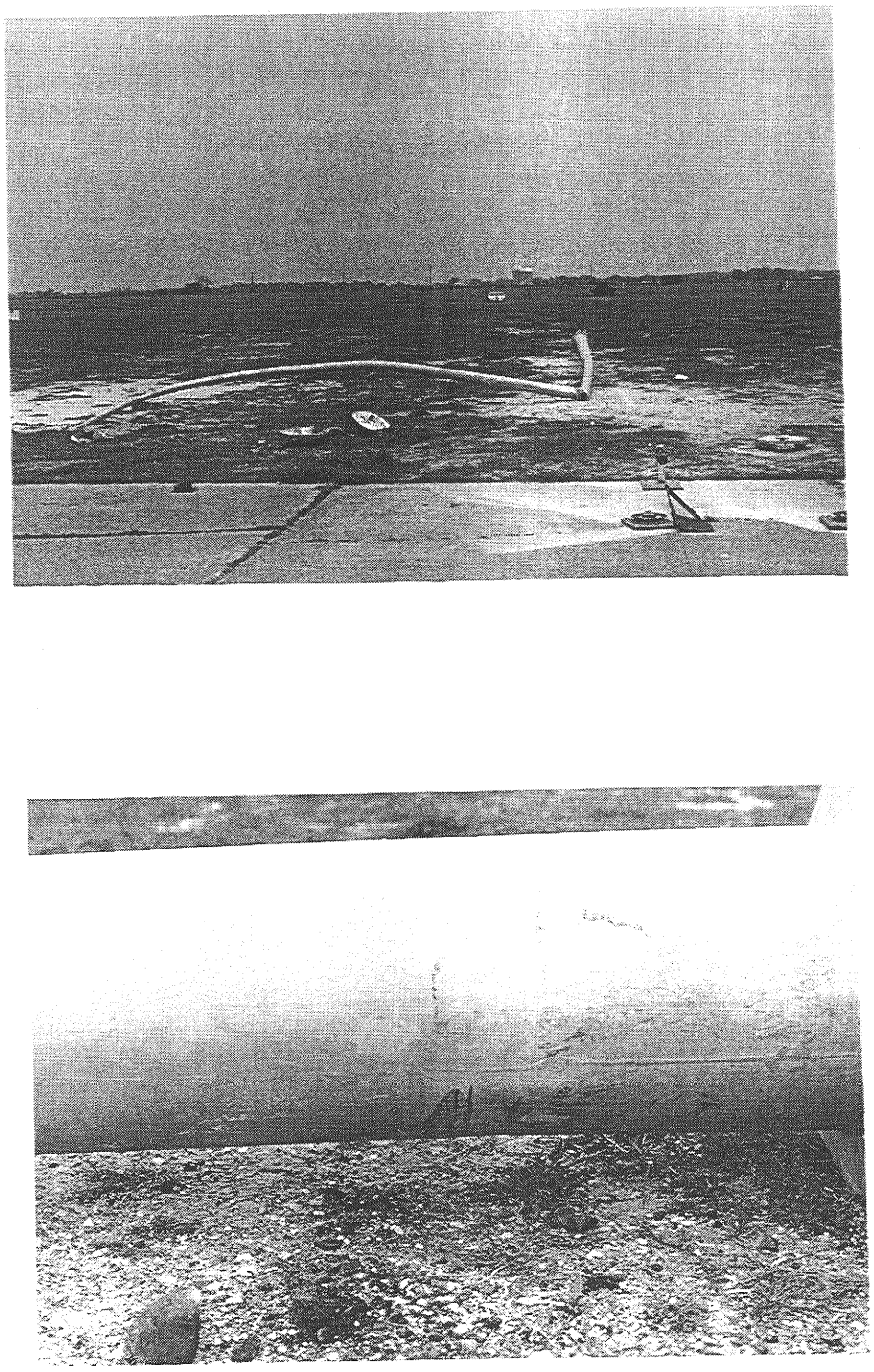


Figure 9. Slip-away base luminaire support installation after test 472360-1.

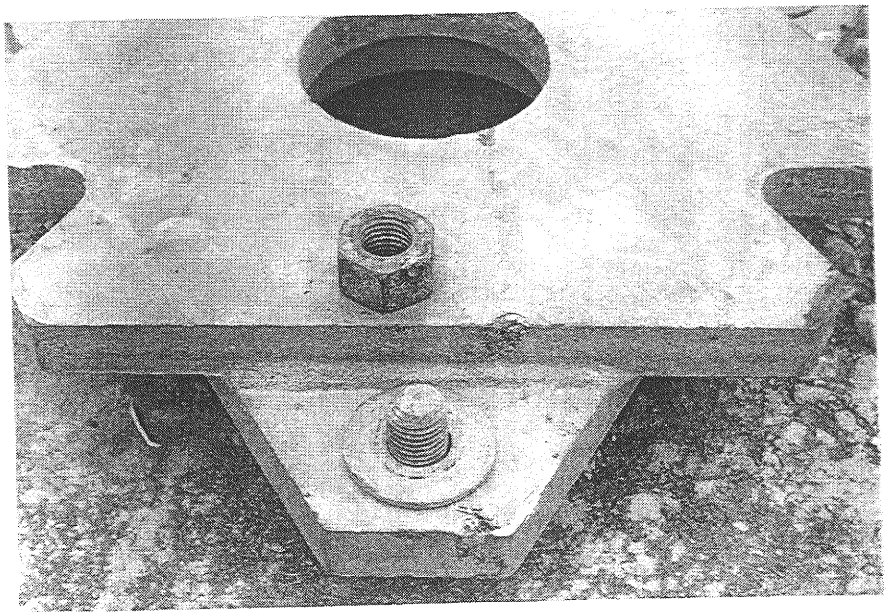


Figure 10. Damage to slip-base (test 472360-1).

Exterior body damage sustained by the vehicle during the impact is shown in Figure 11. There was damage to the front bumper, grill, hood, and radiator. A maximum crush of 240 mm (9.4 in) was recorded at the front center of the vehicle. As shown in Figure 12, the front stabilizer bar and oil pan were bent from contact with the front anchor bolt of the foundation base plate assembly. There was no deformation or intrusion into the occupant compartment of the vehicle.

Data from the accelerometer located at the center-of-gravity were digitized and occupant risk factors were computed as follows. In the longitudinal direction, occupant impact velocity was 5.0 m/s (16.4 ft/s) at 0.161 s, the highest 0.010-s average ridedown acceleration was -1.6 g between 0.171 and 0.181 s, and the maximum 0.050-s average acceleration was -8.7 g between 0.003 and 0.053 s. In the lateral direction, occupant impact velocity was -0.6 m/s (-1.8 ft/s) at 0.909 s, the highest 0.010-s occupant ridedown acceleration was -0.3 g between 0.919 and 0.929 s and the maximum 0.050-s average acceleration was -0.6 g between 0.021 and 0.071 s. These data and other pertinent information from the test are summarized in Figure 13. Vehicular angular displacements are displayed in Figure 14. Vehicular accelerations versus time traces filtered digitally at 60 Hz are presented in Figures 15 through 17.

In summary, the results of this test were judged to be in compliance with recommended performance criteria for luminaire supports as presented in NCHRP Report 350. The slip-base mechanism activated readily, allowing the vehicle to travel under the rotating pole. The test vehicle remained upright and stable during the impact event and after loss of contact with the test article. The occupant impact velocity in the longitudinal direction was 5.0 m/sec (16.4 ft/sec) which is equivalent to the maximum permissible value established by NCHRP Report 350. Although this value is on the border of allowable performance, all other evaluation criteria were easily satisfied and the test was judged to be acceptable. A summary of pertinent *NCHRP Report 350* evaluation criteria for this test is shown in Table 2.

Test 472360-2 (Low-Speed Test)

The test vehicle, shown in Figure 18, was a 1988 Chevrolet Sprint. Test inertia weight of the vehicle was 820 kg (1,808 lb) and its gross static weight was 896 kg (1,975 lb). The height to the lower edge of the vehicle bumper was 32 cm (12.6 in) and the height to the top of

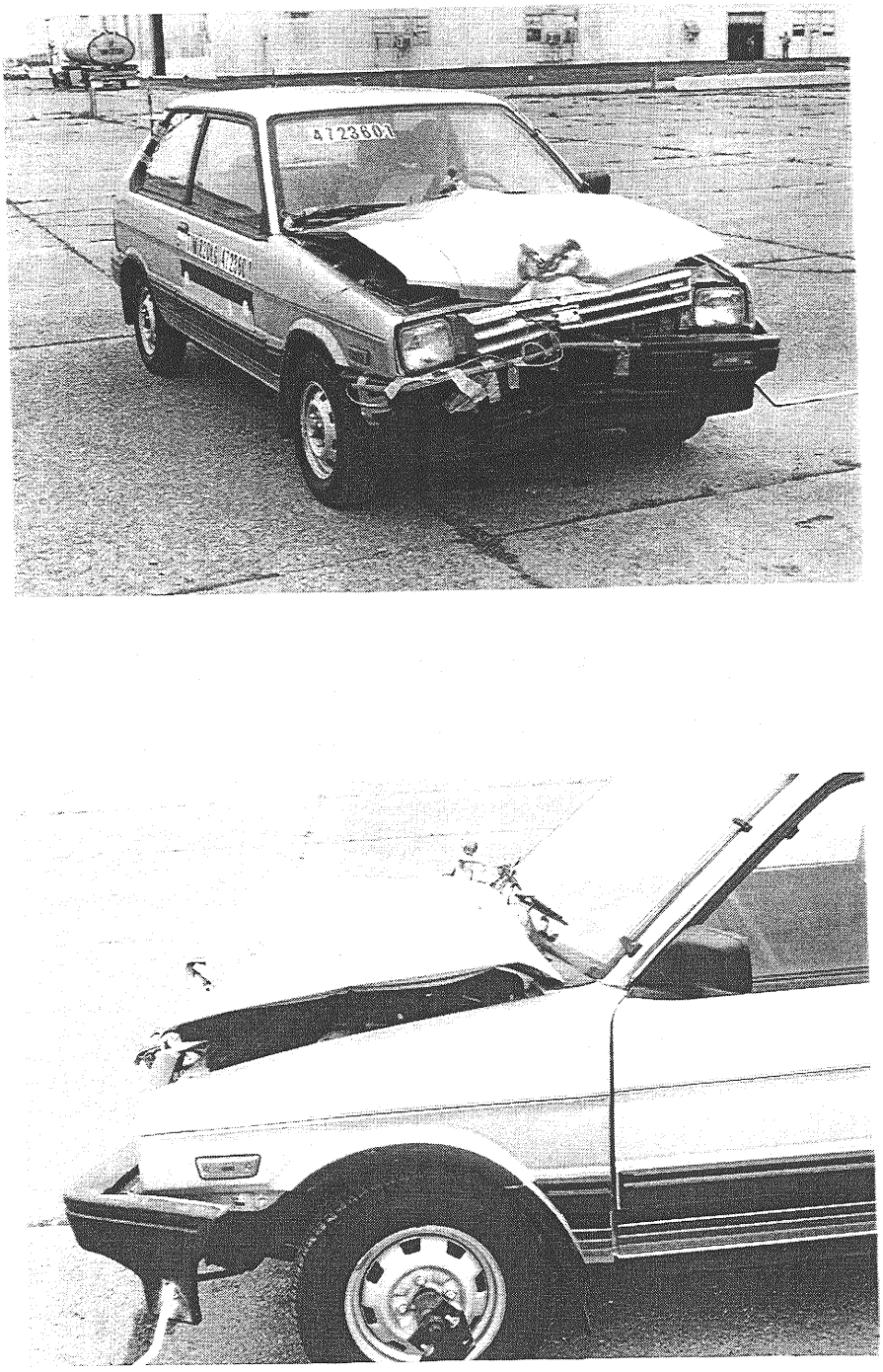


Figure 11. Vehicle after test 472360-1.

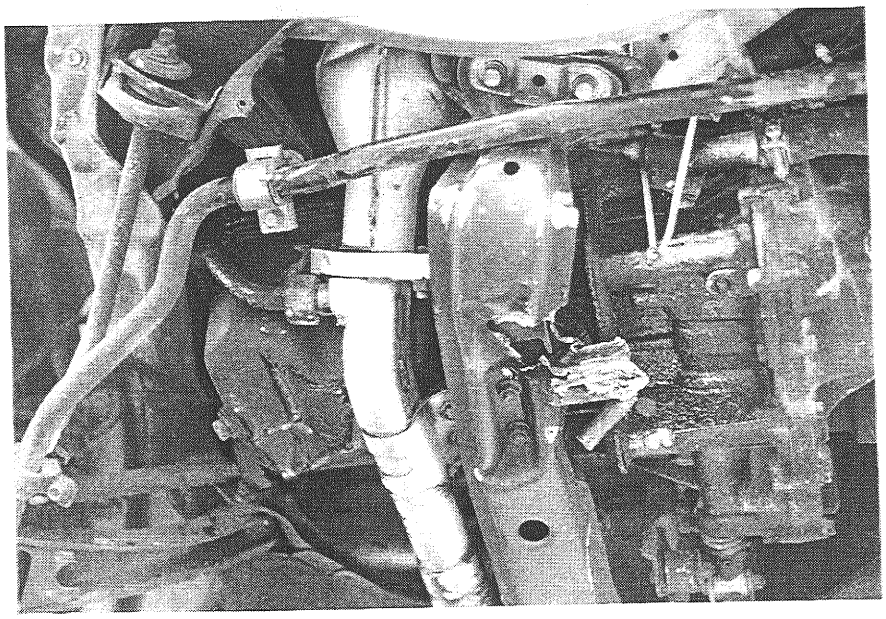
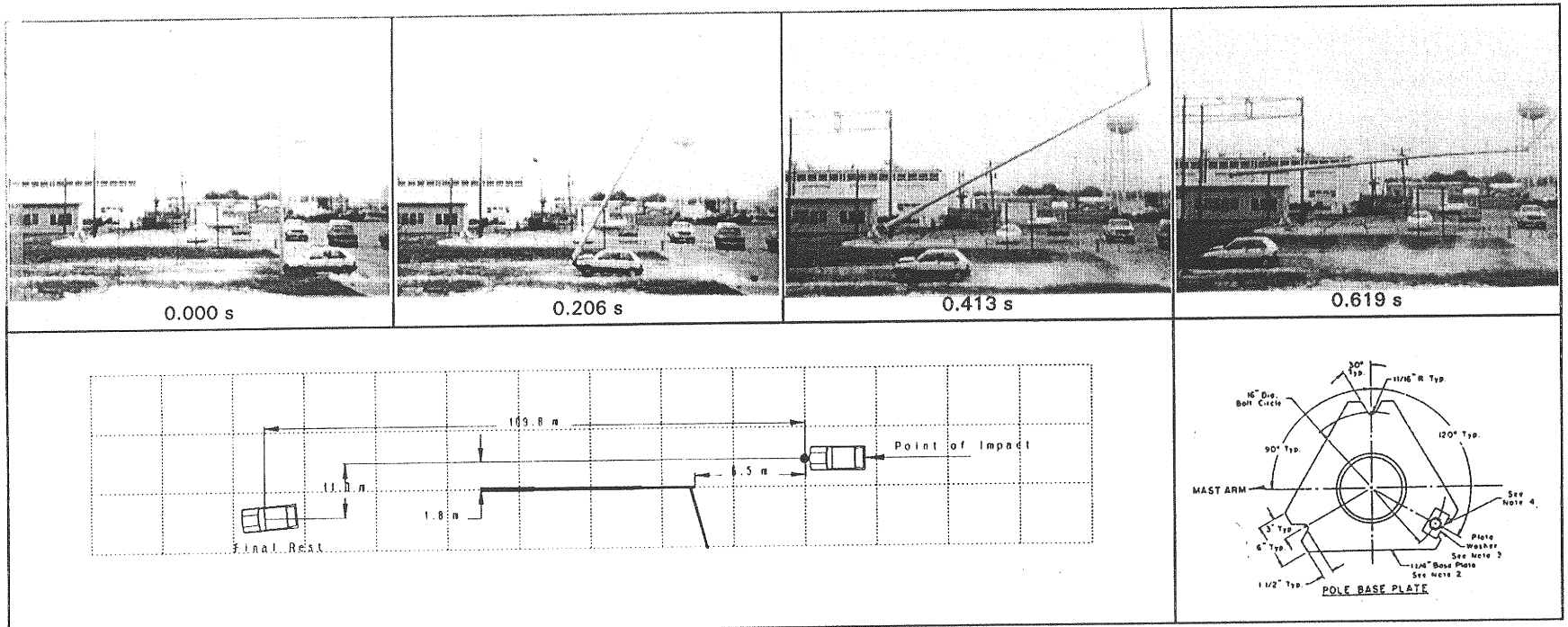


Figure 12. Damage to undercarriage of vehicle (test 472360-1).



General Information

Test Agency	Texas Transportation Institute
Test No.	472360-1
Date	03/24/94

Test Article

Type	Luminaire Support
Name or Manufacturer	Arizona Slip-away base
Installation Length (m)	13.7 m (45.0 ft)
Size and/or dimension and material of key elements	steel pole
Soil Type and Condition	Concrete Footing

Test Vehicle

Type	Production Model
Designation	820 C
Model	1988 Subaru Justy
Mass (kg) Curb	773 (1,704 lb)
Test Inertial	820 (1,808 lb)
Dummy	75 (165 lb)
Gross Static	893 (1,969 lb)

Impact Conditions

Speed (km/h)	102.2 (63.5 mi/h)
Angle (deg)	0

Exit Conditions

Speed (km/h)	N.A.
Angle (deg)	N.A.

Occupant Risk Values

Impact Velocity (m/s)	
x-direction	5.0 (16.4 ft/s)
y-direction	-0.6 (-1.8 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-1.6
y-direction	-0.3
PHD (optional)	
ASI (optional)	
Max. 0.050-sec Averages (g's)	
x-direction	-8.7
y-direction	-0.6
z-direction	-3.6

Test Article Deflections (m)

Dynamic	N.A.
Permanent	N.A.

Vehicle Damage

Exterior	
VDS	12FC-4
CDC	12FCEN1
Interior	
OCDI	AS0000000
Maximum Exterior Vehicle Crush (mm)	240 (9.4 in)
Max. Occ. Compart. Deformation (mm)	0

Post-Impact Behavior

Max. Roll Angle (deg)	-2.5
Max. Pitch Angle (deg)	5.0
Max. Yaw Angle (deg)	3.1

Figure 13. Summary of results for test 472360-1.

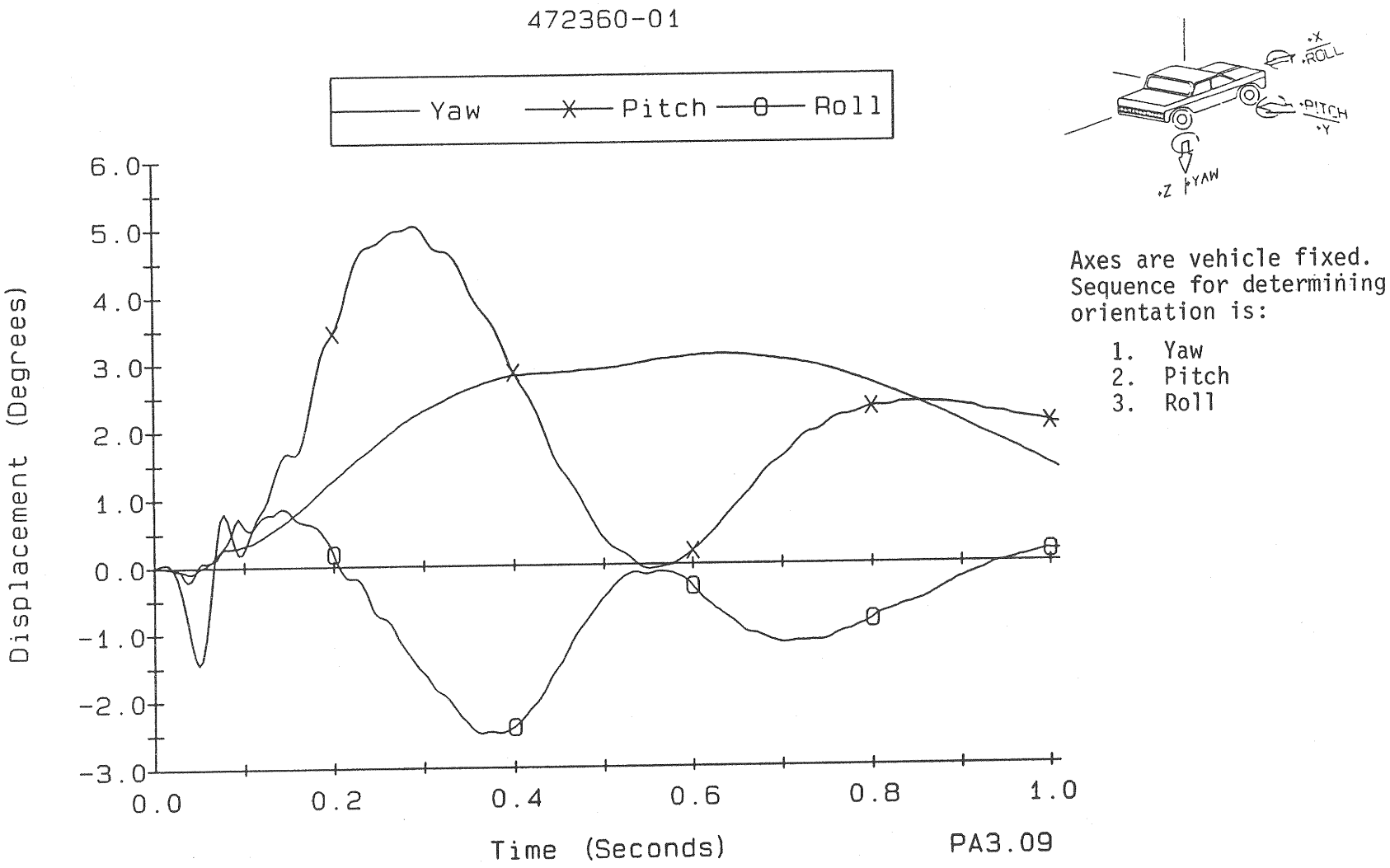


Figure 14. Vehicle angular displacements during test 472360-1.

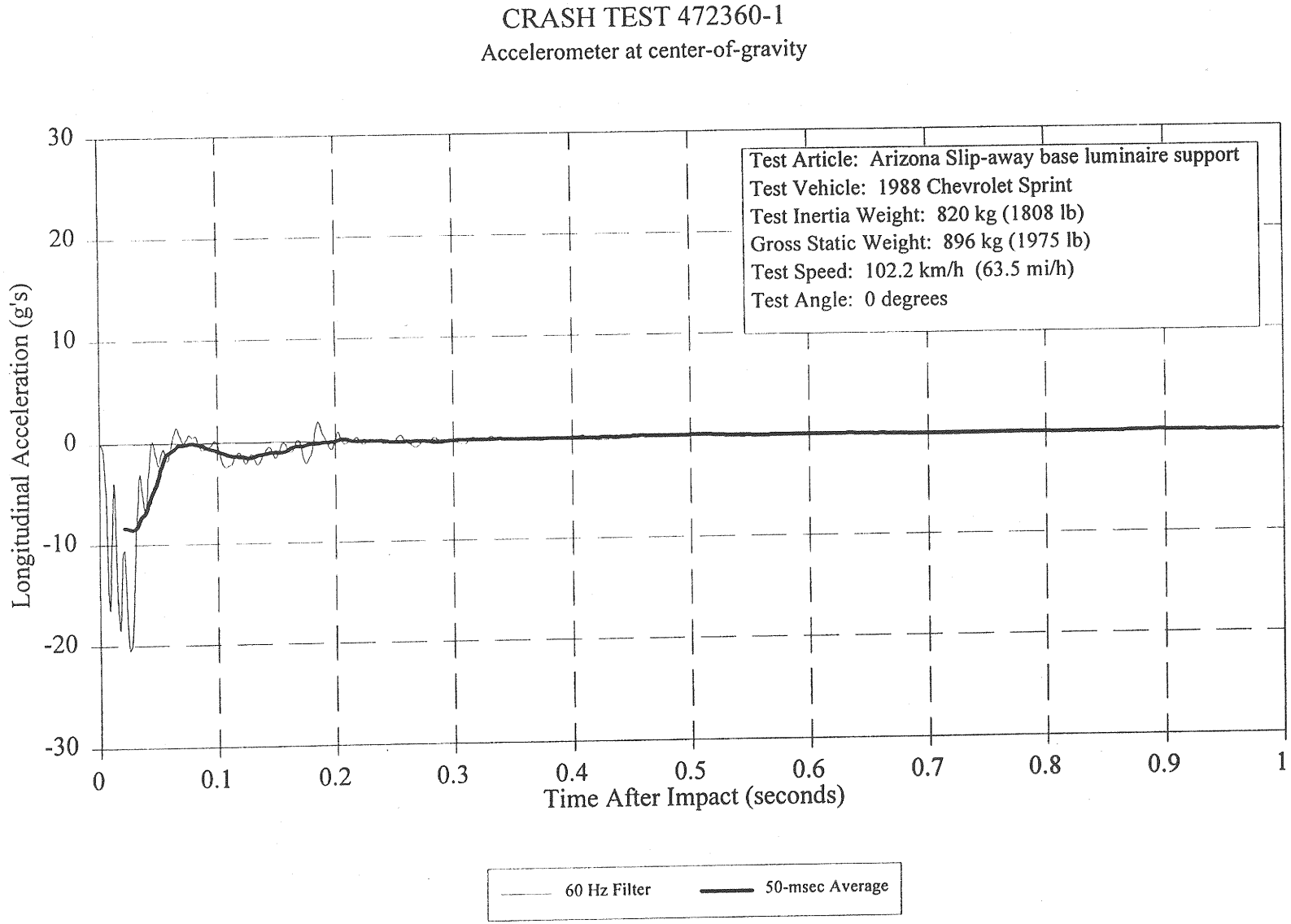


Figure 15. Vehicle longitudinal accelerometer trace for test 472360-1.

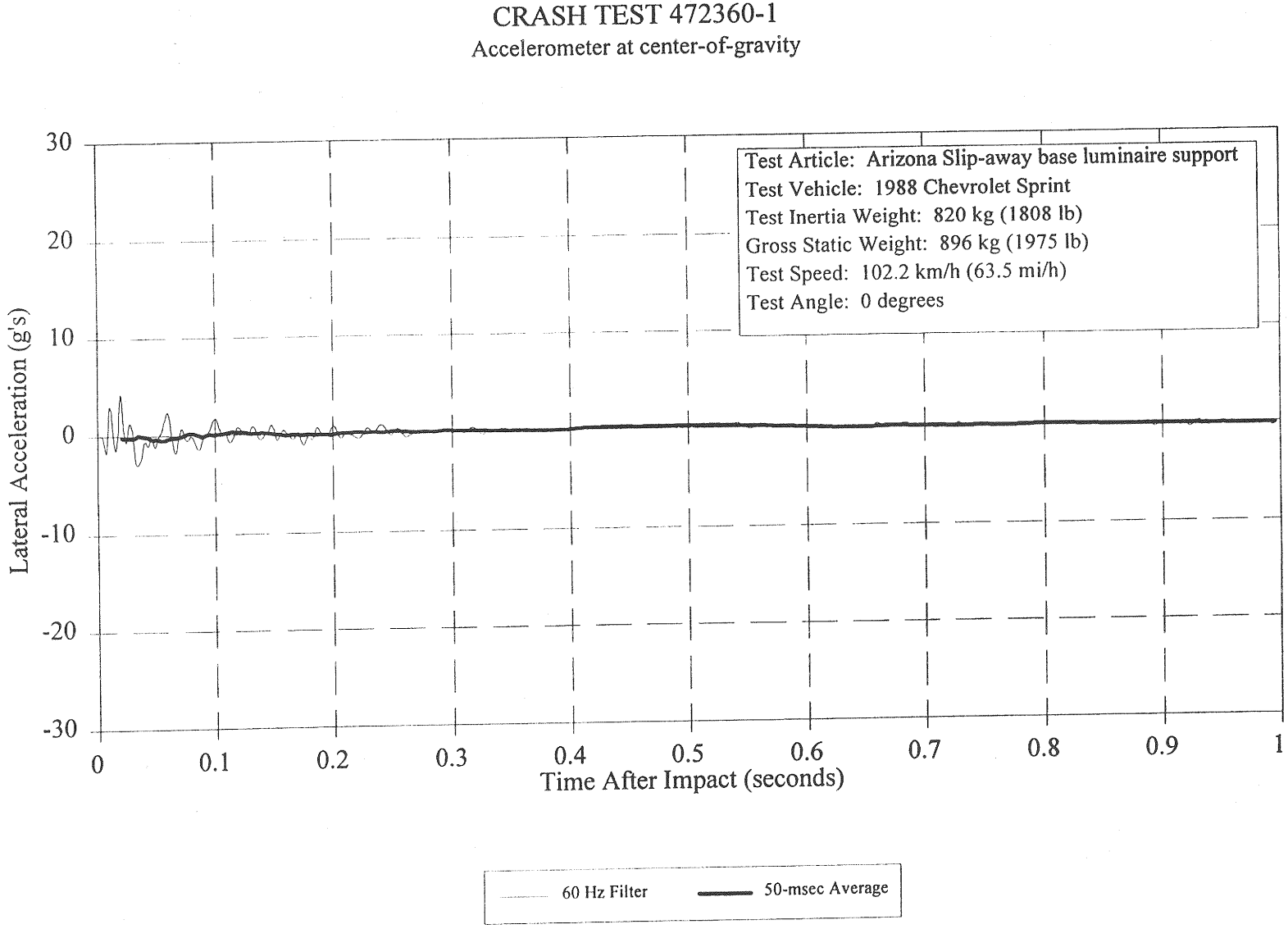


Figure 16. Vehicle lateral accelerometer trace for test 472360-1.

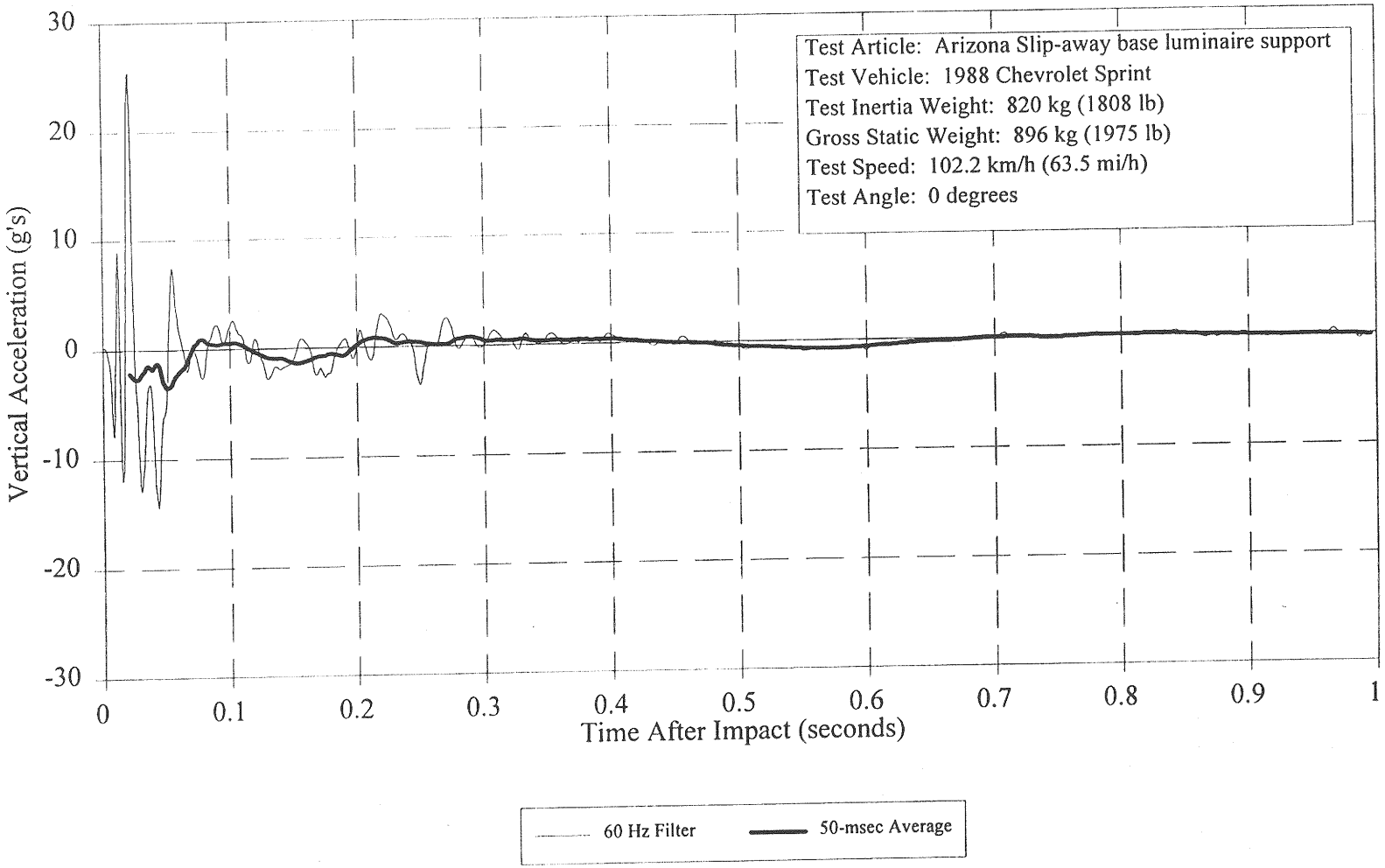


Figure 17. Vehicle vertical accelerometer trace for test 472360-1.

Table 2. Summary of NCHRP Report 350 evaluation criteria for test 72360-1

Test No.: 472360-1 Test Date: 03/24/94 Test Agency: Texas Transportation Institute

Evaluation Criteria	Test Results	Assessment
Structural Adequacy B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.	The luminaire support yielded by disengaging the slip-plate bolts attaching the mating surfaces of the slip-away base plates.	Pass
Occupant Risk D. Detached elements should not penetrate the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of the occupant compartment that could cause serious injuries should not be permitted.	The luminaire detached from the mast arm but **did not** present a hazard to other travel lanes. There was **no** deformation of or intrusion into the occupant compartment.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright and stable throughout the test period.	Pass
H. Occupant impact velocities should satisfy the following: Occupant Impact Velocity Limits (m/s) Component / Preferred / Maximum Longitudinal and Lateral / 9 / 12	Longitudinal occupant impact velocity: 5.0 m/s (16.4 ft/s) Lateral occupant impact velocity: -0.6 m/s (-1.8 ft/s)	Pass
I. Occupant ridedown accelerations should satisfy the following Occupant Ridedown Acceleration Limits (G's) Component / Preferred / Maximum Longitudinal and Lateral / 15 / 20	Longitudinal Occupant Ridedown Acceleration: -1.6 g's Lateral Occupant Ridedown Acceleration: -0.3 g's	Pass
Vehicle Trajectory K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle trajectory was judged to be acceptable.	Pass

Figure 18. Vehicle prior to test 472360-2.

the bumper was 50 cm (19.7 in). The position of the vehicle relative to the luminaire pole is shown in Figure 19. Additional dimensions and information pertaining to the test vehicle are given in Figure 20. The vehicle was directed into the guardrail system using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact.

The vehicle impacted the luminaire support with the centerline of the vehicle aligned with the centerline of the support at a speed of 35.8 km/h (22.2 mi/h) and a zero degree heading angle. Upon impact, the slip base activated readily as designed. At 0.201 s, the luminaire detached from the mast arm and began to fall to the ground. The vehicle initially lost contact with the pole about 0.213 s after impact. The travel speed of the vehicle at loss of contact was 23.0 km/h (14.3 mi/h). The rotational velocity of the luminaire support was approximately 55.5 deg/sec. As the luminaire support descended in front of the vehicle, the front of the vehicle reengaged the luminaire support at approximately 0.450 s. The luminaire support was once again displaced upward and forward of the vehicle's position. At 1.259 s, the front of the vehicle struck the luminaire support a third time. This time the luminaire pole rotated onto the vehicle resulting in substantial crushing of the roof. The upper end of the luminaire support came into contact with the roadway, causing the base of the support to momentarily disengage from the roof of the vehicle. The base of the pole then recontacted the roof structure, resulting in further deformation. The base of the support eventually snagged on the rear-hatch and remained in contact with the vehicle as it came to final rest 20.9 m (68.5 ft) downstream from the initial point of impact. Sequential photographs of the impact event are shown in Figure 21.

As can be seen in Figure 22, the support sustained minimal damage from the impact. The mast arm became detached from the luminaire pole due to contact with the ground, and the top of the pole was deformed.

Figure 23 shows the damage to the test vehicle. The vehicle received a maximum crush of 200 mm (7.9 in) at the front center of the vehicle. The crush sustained to the roof spanned an area of 1000 mm (39.4 in) wide x 1500 mm (59.1 in) long, with the maximum depth of penetration measured to be 165 mm (6.5 in) at the aft edge of the roof. The crush sustained by the roof was sufficient enough to cause the A, B, and C pillars to be bent inward on both sides

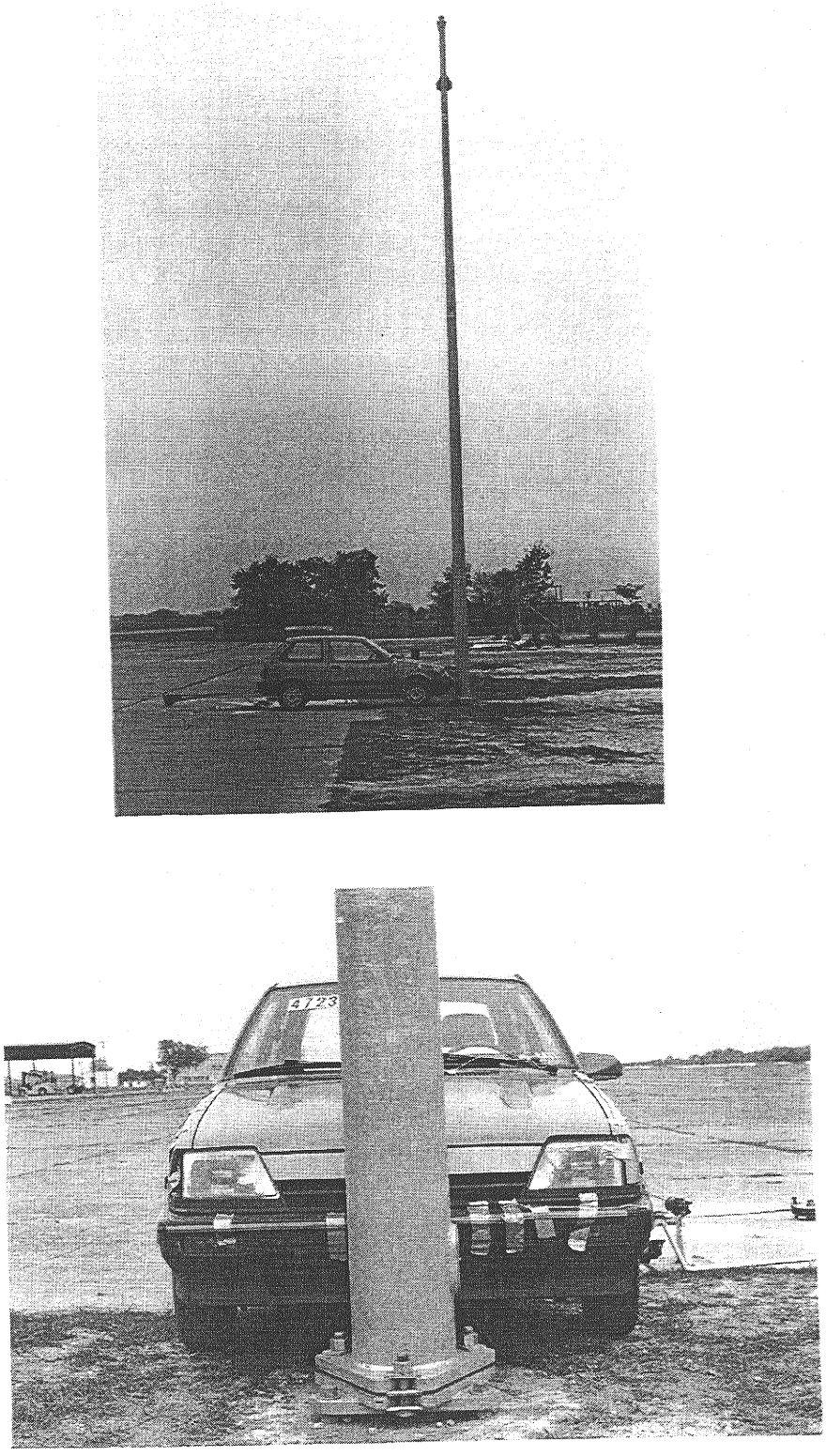


Figure 19. Vehicle/test installation geometrics for test 472360-2.

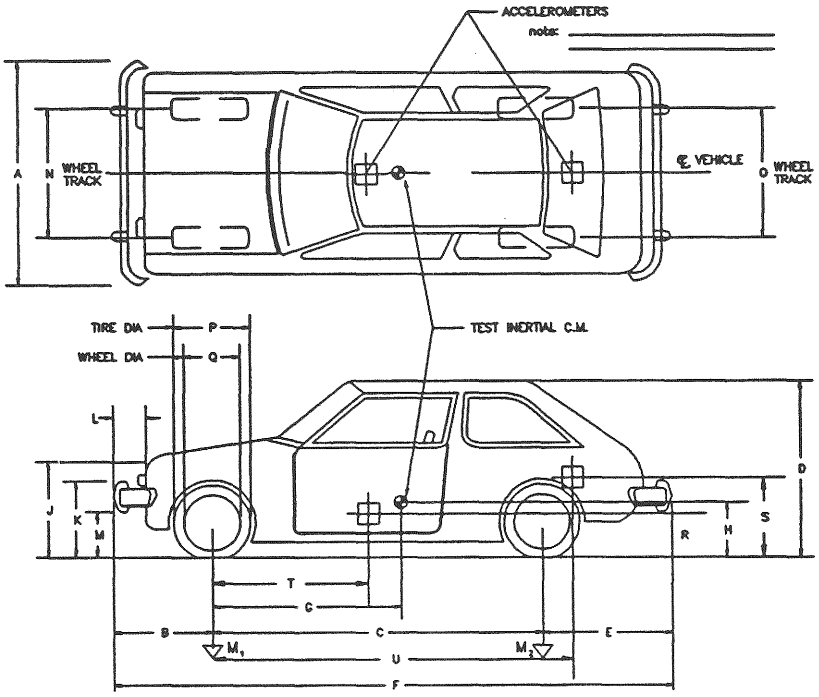
DATE: 3-25-94 TEST NO.: 472360-2 VIN NO.: JG1MR2150JK720927 MAKE: Chevy

MODEL: Sprint YEAR: 1988 ODOMETER: 8712 TIRE SIZE: 155 R12

TIRE INFLATION PRESSURE: _____

MASS DISTRIBUTION (kg) LF 248 RF 249 LR 167 RR 156

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



ENGINE TYPE: 3 cyl Gas

ENGINE CID: 1.0 L

TRANSMISSION TYPE:

X AUTO

_ MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: _____

MASS: _____

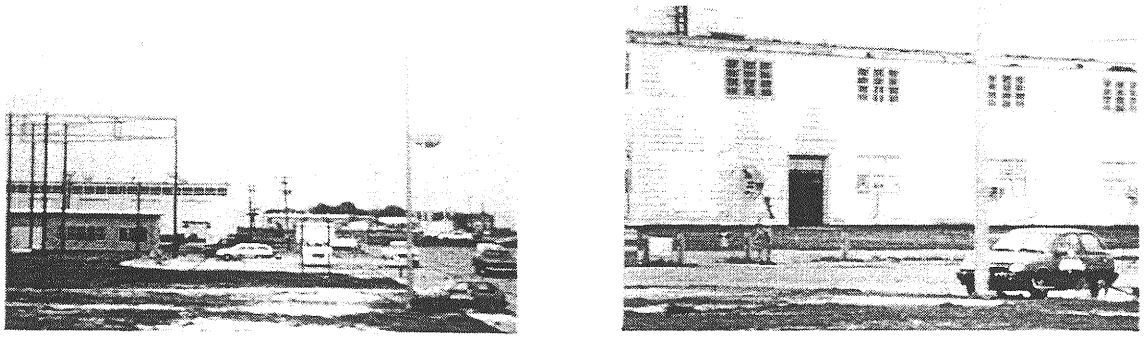
SEAT POSITION: _____

GEOMETRY – (mm)

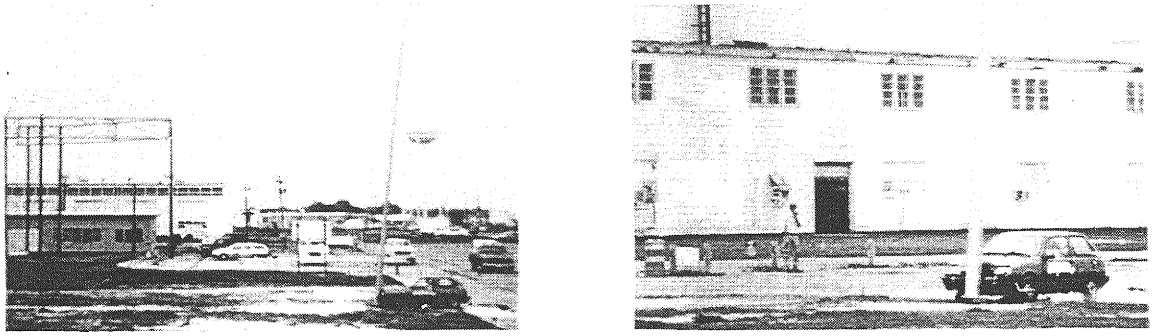
A	1450	E	650	J	720	N	1340	R	380
B	720	F	3620	K	500	O	1300	S	720
C	2250	G	886	L	170	P	550	T	930
D	1320	H		M	320	Q	350	U	2610

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	463	497	533
M_2	256	323	363
M_T	719	820	896

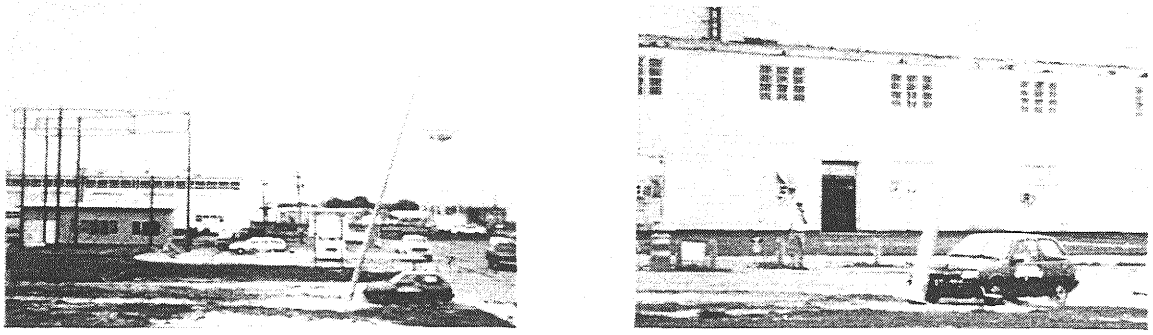
Figure 20. Vehicle properties for test 472360-2.



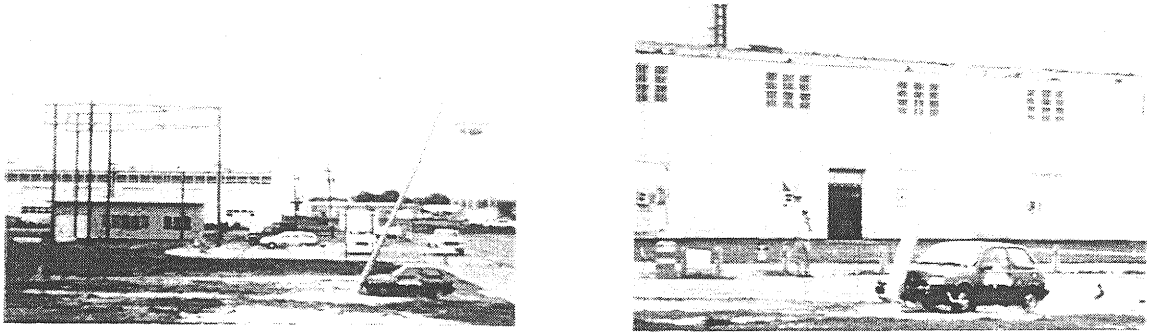
0.000 s



0.174 s



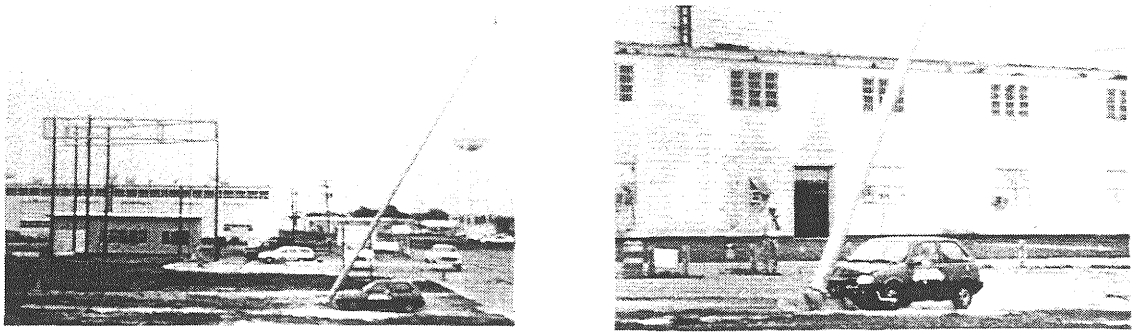
0.348 s



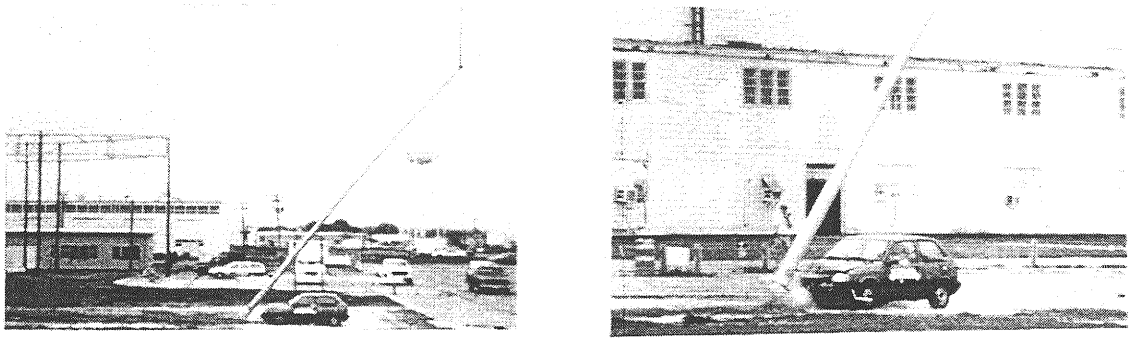
0.522 s

Figure 21. Sequential photographs for test 472360-2.

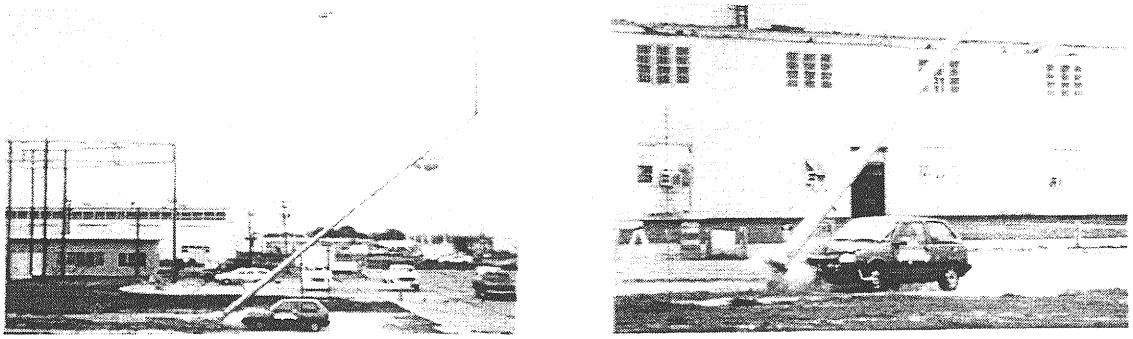
(perpendicular and downstream angular views)



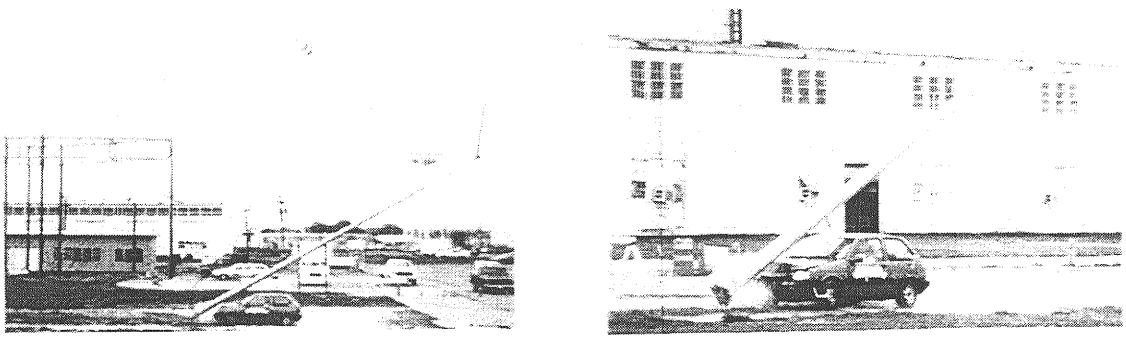
0.696 s



0.870 s



1.004 s



1.218 s

Figure 21. Sequential photographs for test 472360-1 continued.

(perpendicular and downstream angular views)

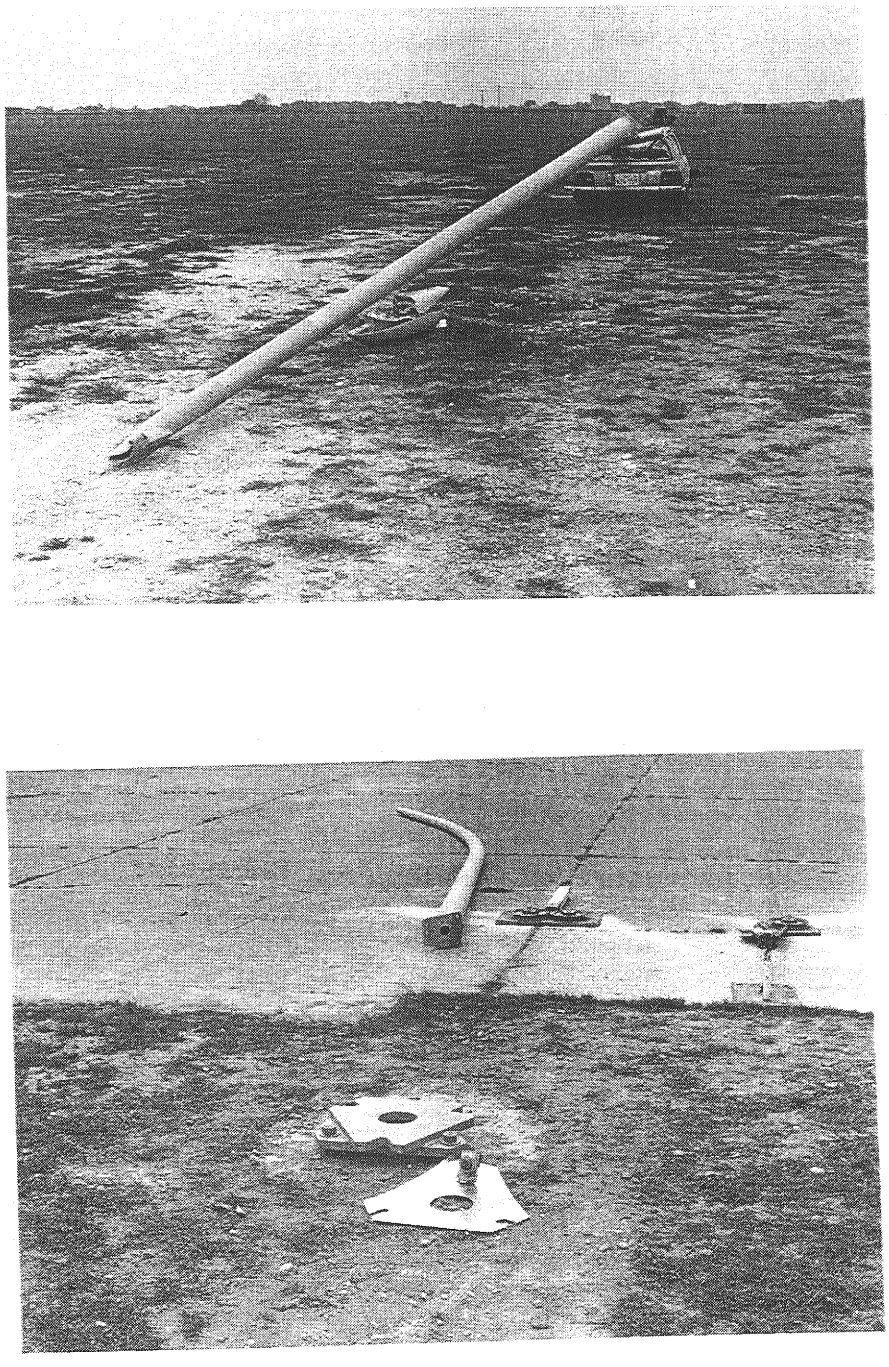


Figure 22. Slip-away base luminaire support installation after test 472360-2.

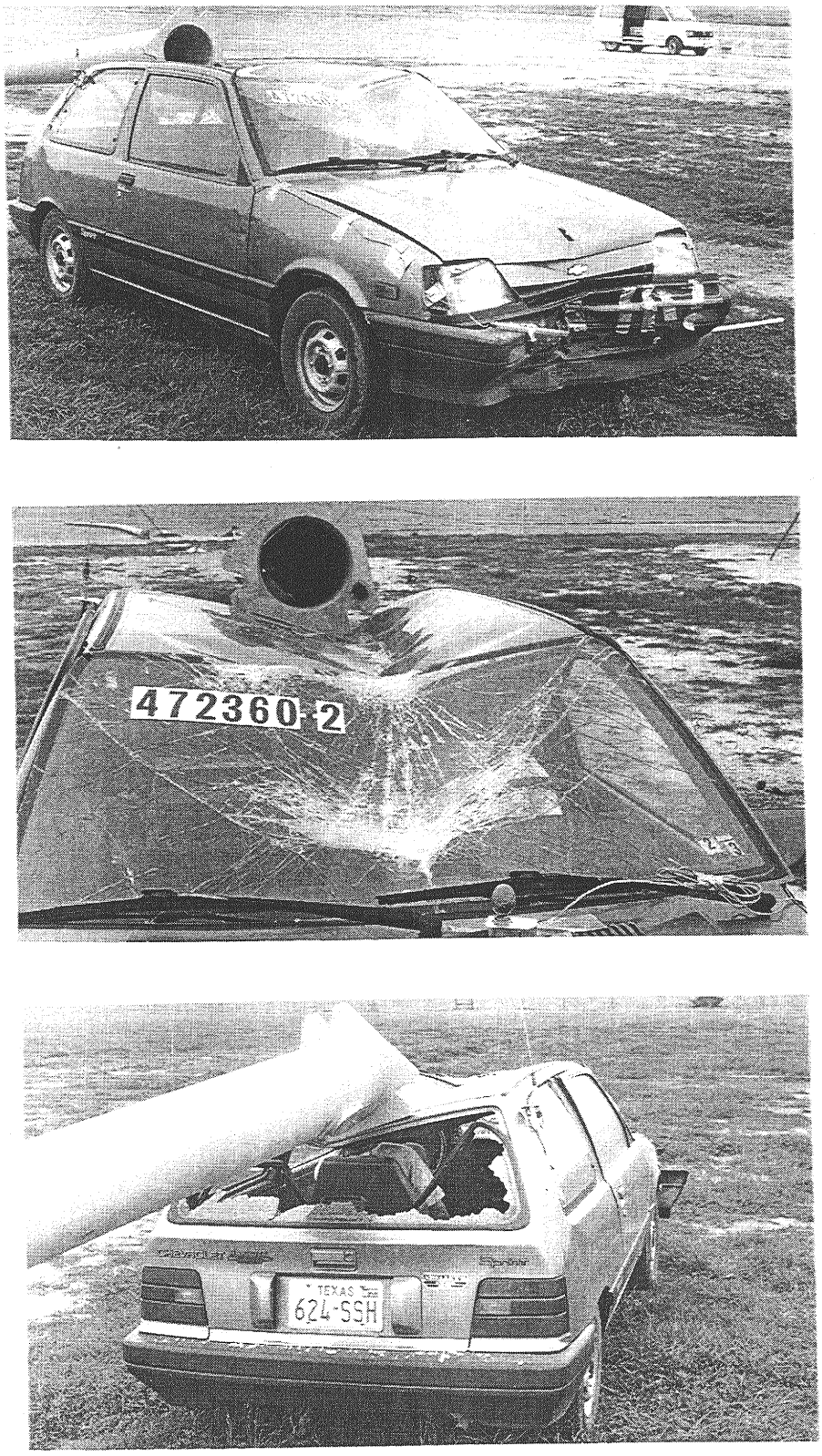


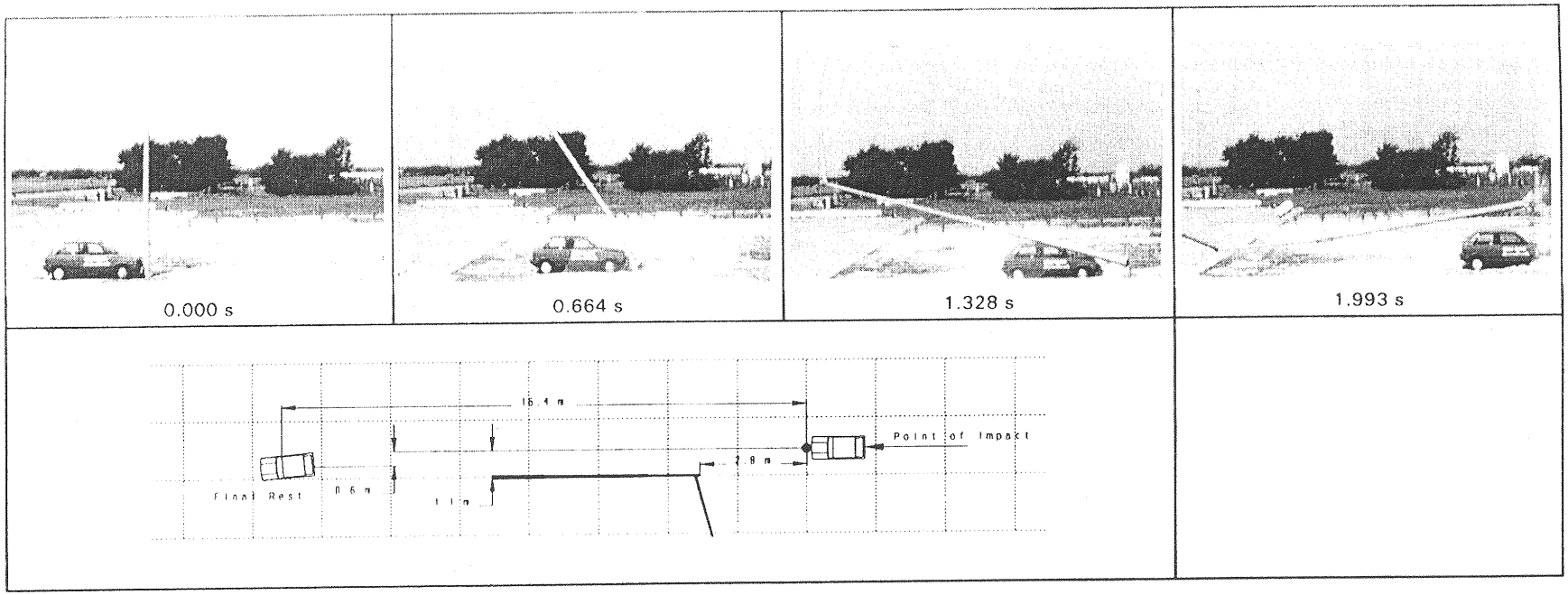
Figure 23. Vehicle after test 472360-2.

of the vehicle. Additionally, the vehicle sustained damage to the front bumper, grill, hood, and rear hatch.

Data from the accelerometer located at the center-of-gravity were digitized for evaluation of occupant risk and were computed as follows. In the longitudinal direction, occupant impact velocity was 2.6 m/s (8.6 ft/s) at 0.276 s, the highest 0.010-s average ridedown acceleration was -3.2 g between 0.542 and 0.552 s, and the maximum 0.050-s average acceleration was -4.7 g between 0.004 and 0.054 s. In the lateral direction, occupant impact velocity was -0.3 m/s (-1.0 ft/s) at 1.454 s, the highest 0.010-s occupant ridedown acceleration was 1.5 g between 1.726 and 1.736 s, and the maximum 0.050-s average acceleration was 0.7 g between 0.040 and 0.090 s. These data and other pertinent information from the test are summarized in Figure 24. Vehicular angular displacements are displayed in Figure 25. Vehicular accelerations versus time traces filtered digitally at 60 Hz are presented in Figures 26 through 28.

In test 472360-2, the slip base activated as designed and the luminaire support readily yielded to the vehicle. The occupant impact velocities and ridedown accelerations were less than those recorded for the high-speed test and were well within the recommended limits set forth in *NCHRP Report 350*. However, the secondary impact of the pole with the roof of the vehicle resulted in substantial deformation of the roof structure. The crush to the roof, which was measured to be 165 mm (6.5 in), violated the integrity of the occupant compartment and the test was judged to be a failure on this basis. An *NCHRP Report 350* evaluation summary of test 472360-2 is shown in Table 3.

In summary, it was concluded that ADOT's standard 13.7-m (45-ft) constant tapered luminaire pole does not meet current impact performance guidelines set forth in NCHRP Report 350. It can also be inferred from this test that the other 13.7-m (45-ft) pole designs, which weigh more than the constant tapered design which was tested, would also exhibit unacceptable behavior. Therefore, in order to achieve a mounting height comparable to that provided by the standard 13.7-m (45-ft) pole, other design alternatives must be investigated. This issue is addressed in the next section of the report.



General Information
- Test Agency . . . . . Texas Transportation Institute
- Test No. 472360-3
- Date 04/18/94

Test Article
- Type . . . . . Luminaire Support
- Name or Manufacturer: Arizona Slip-away base
- Installation Length (m): 12.2 m (40.0 ft)
- Size and/or dimension and material of key elements . . . . . steel pole

Soil Type and Condition . . Concrete Footing

Test Vehicle
- Type . . . . . Production Model
- Designation . . . . . 820 C
- Model . . . . . 1988 Subaru Justy
- Mass (kg) Curb . . . . . 758 (1,671 lb)
  - Test Inertial 820 (1,808 lb)
  - Dummy . . . 75 (165 lb)
  - Gross Static 895 (1,973 lb)

Impact Conditions
- Speed (km/h) . . . . . 35.7 (22.2 mi/h)
- Angle (deg) 0

Exit Conditions
- Speed (km/h) 10.8 (6.7mi/h)
- Angle (deg) . . . . . N.A.

Occupant Risk Values
- Impact Velocity (m/s)
  - x-direction . . . . . 2.8 (9.3 ft/s)
  - y-direction . . . . . 0.3 (-0.8 ft/s)
- THIV (optional) . . . . .
- Ridedown Accelerations (g's)
  - x-direction . . . . . -2.4
  - y-direction . . . . . -0.6
- PHD (optional) . . . . .
- ASI (optional) . . . . .
- Max. 0.050-sec Averages (g's)
  - x-direction . . . . . -4.6
  - y-direction . . . . . -0.3
  - z-direction 1.4

Test Article Deflections (m)
- Dynamic . . . . . N.A.
- Permanent . . . . . N.A.

Vehicle Damage
- Exterior
  - VDS 12FC-4
  - CDC 12FCEN1
- Interior
  - OCDI AS0200000
- Maximum Exterior Vehicle Crush (mm): 55 (2.2 in)
- Max. Occ. Compart. Deformation (mm) . 120 (4.7 in)

Post-Impact Behavior
- Max. Roll Angle (deg): -0.7
- Max. Pitch Angle (deg): 1.3
- Max. Yaw Angle (deg): 1.6

Figure 24. Summary of results for test 472360-3.

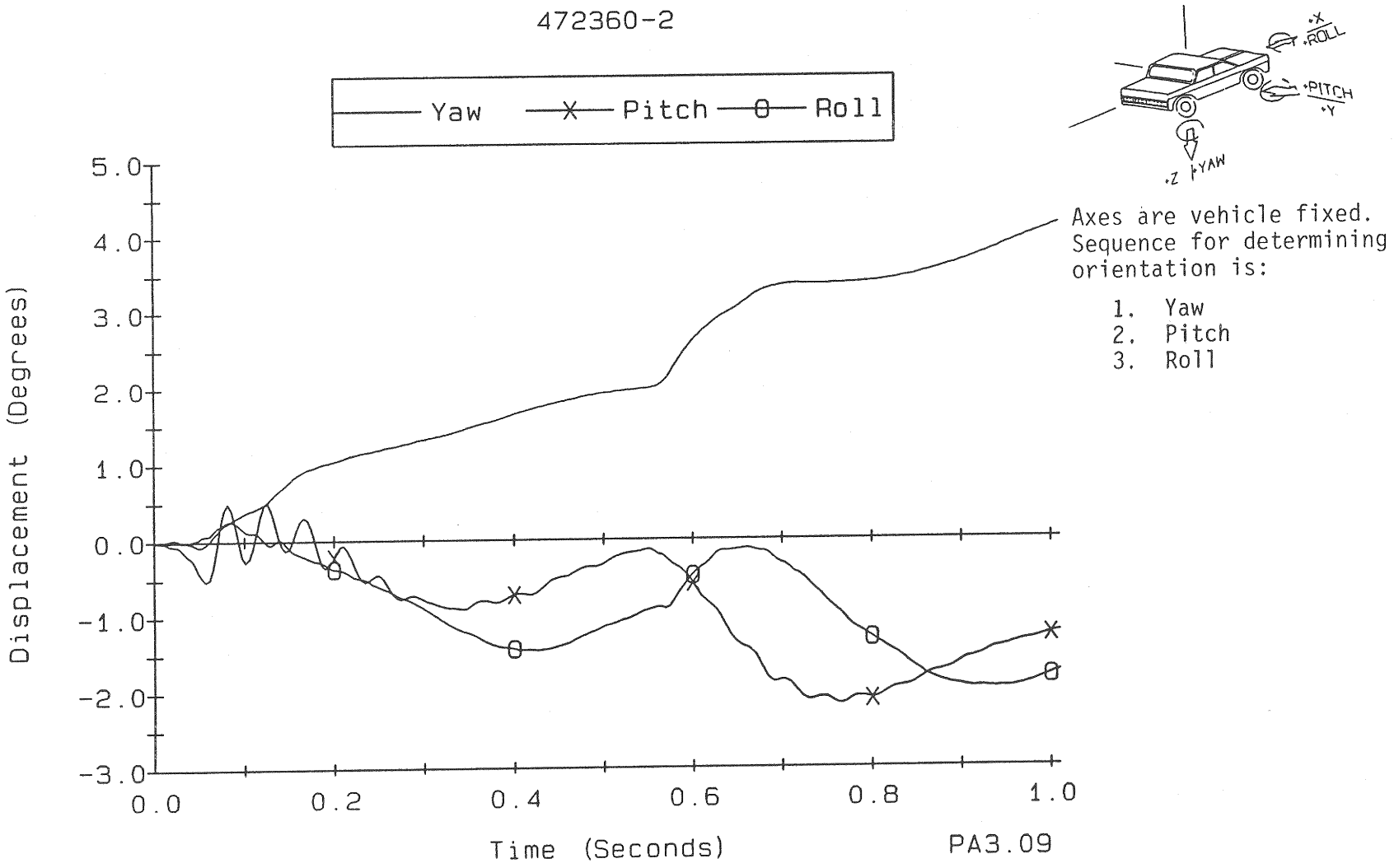


Figure 25. Vehicle angular displacements during test 472360-2.

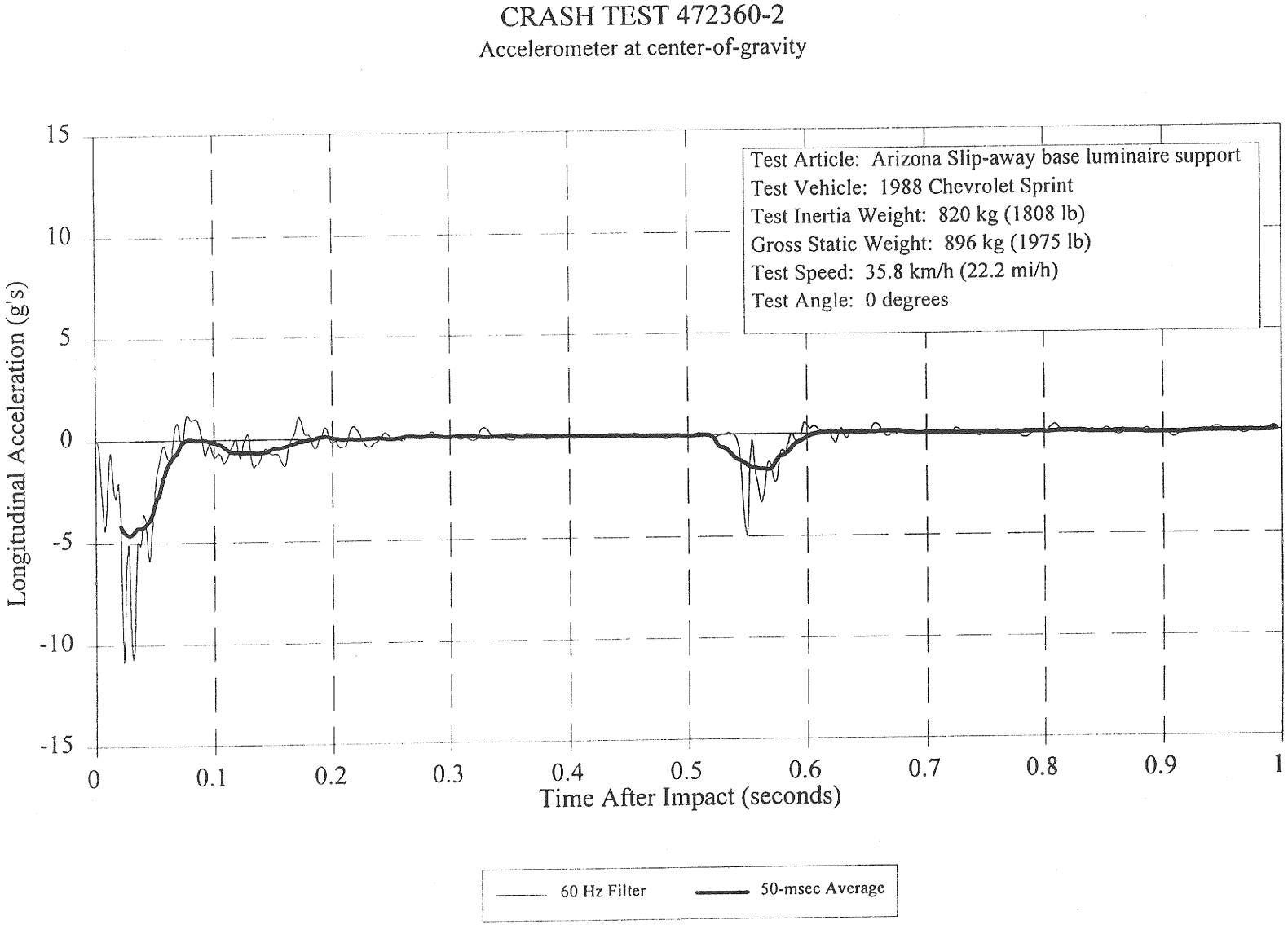


Figure 26. Vehicle longitudinal accelerometer trace for test 472360-2.

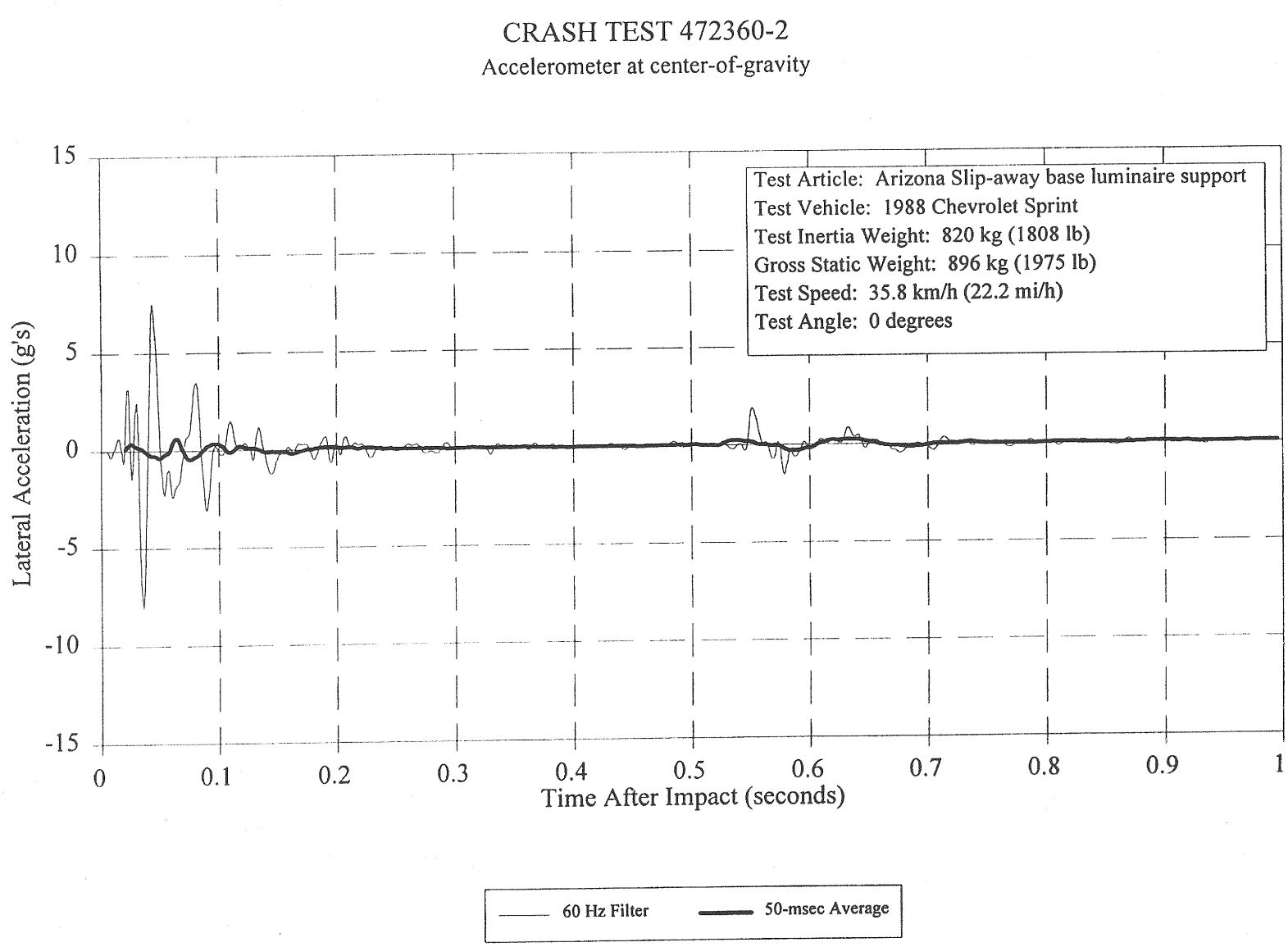


Figure 27. Vehicle lateral accelerometer trace for test 472360-2.

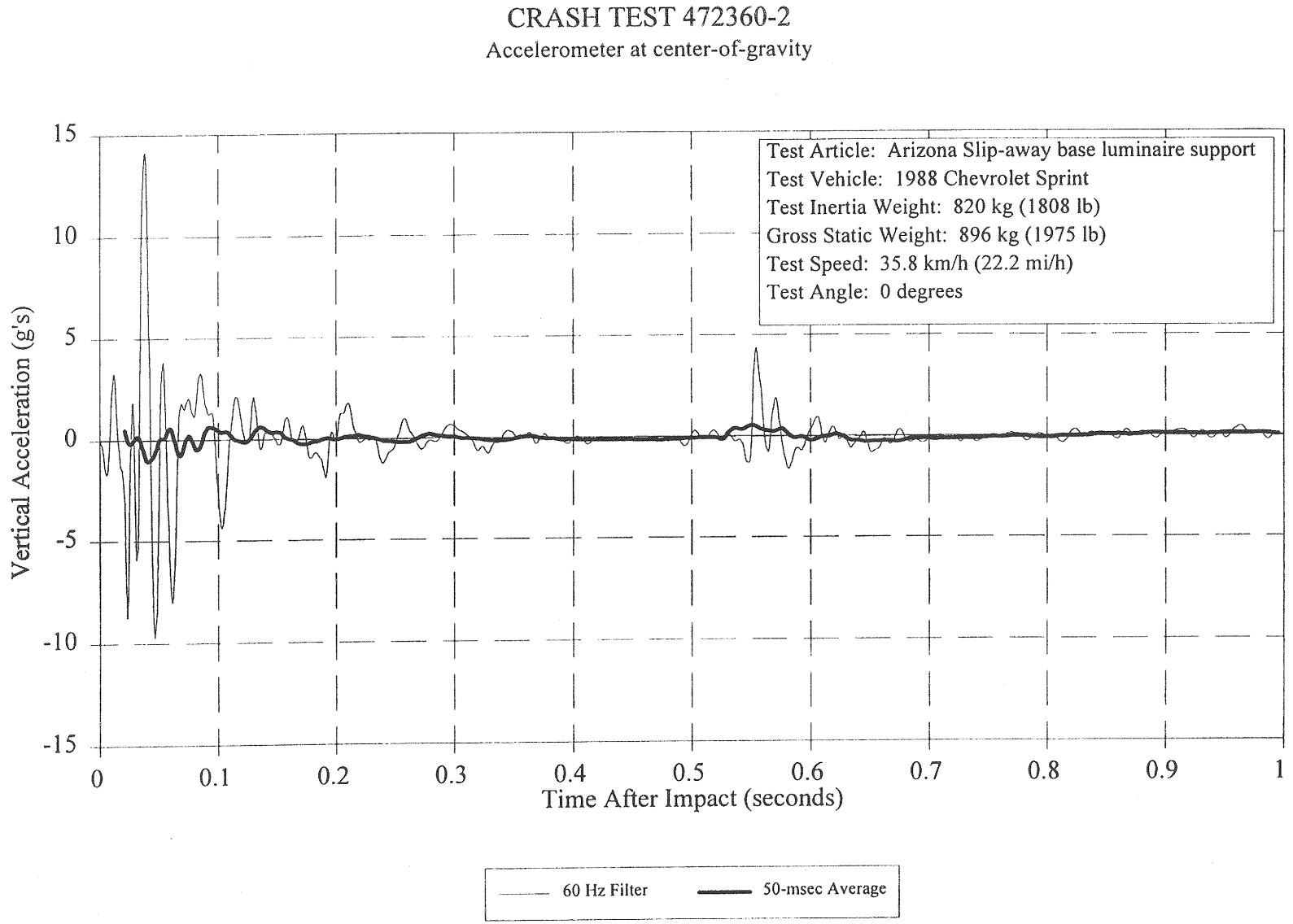


Figure 28. Vehicle vertical accelerometer trace for test 472360-2.

Table 3. Summary of NCHRP Report 350 evaluation criteria for test 72360-2

Test No.: 472360-2 Test Date: 03/25/94 Test Agency: Texas Transportation Institute

Evaluation Criteria	Test Results	Assessment
Structural Adequacy B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.	The luminaire support yielded by disengaging the slip-plate bolts attaching the mating surfaces of the slip-away base plates.	Pass
Occupant Risk D. Detached elements should not penetrate the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of the occupant compartment that could cause serious injuries should not be permitted.	The luminaire detached from the mast arm but **did not** present a hazard to other travel lanes. However, there was **severe** deformation of or intrusion into the occupant compartment from the roof crush.	Fail
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright and stable throughout the test period.	Pass
H. Occupant impact velocities should satisfy the following: Occupant Impact Velocity Limits (m/s) Component / Preferred / Maximum Longitudinal and Lateral / 9 / 12	Longitudinal occupant impact velocity: 2.6 m/s (8.6 ft/s) Lateral occupant impact velocity: -0.3 m/s (-1.0 ft/s)	Pass
I. Occupant ridedown accelerations should satisfy the following Occupant Ridedown Acceleration Limits (G's) Component / Preferred / Maximum Longitudinal and Lateral / 15 / 20	Longitudinal Occupant Ridedown Acceleration: -3.2 g's Lateral Occupant Ridedown Acceleration: 1.5 g's	Pass
Vehicle Trajectory K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle trajectory was judged to be acceptable.	Pass

12.2-m (40-ft) Luminaire Support System

Since the 13.7-m (45-ft) luminaire pole was found to be deficient, it was decided to evaluate the impact performance of the next most critical system which is ADOT's standard 12.2-m (40-ft) constant tapered pole. Except for the length, the support pole was similar in design and construction to the previously tested 13.7-m (45-ft) pole. As with the prior test installation, a 6.1 m (20.0 ft) tapered mast arm and luminaire were attached to the luminaire pole. The pole base plate, foundation base plate, and concrete footing were identical to those used in the previous test installation as detailed in Figures 2 and 3. The three slip-base bolts were torqued to a value of 281.8 N-m (208 ft-lb) in accordance with ADOT standards. The total weight of the system, which included the pole, pole base plate, mast arm, and luminaire, was measured to be 385.6 kg (850 lb). Photographs of the completed test installation are shown in Figure 29.

Previous full-scale testing has demonstrated that, for a given slip-base design and bolt torque, the occupant impact velocity tends to decrease with the mass of the pole. Thus, since the 12.2-m (40-ft) system has less total mass than the 13.7-m (45-ft) system, the resulting occupant impact velocity was expected to be less than that caused by an impact with the 13.7-m (45-ft) pole. Since the occupant impact velocity measured during the high-speed test of the 13.7-m (45-ft) pole was within the acceptable limits set forth in NCHRP Report 350, and since the post-impact trajectory of the pole was not an issue, it was concluded that it was unnecessary to repeat the high-speed test for the 12.2-m (40-ft) luminaire support system.

The low-speed test, however, was considered to be critical due to the potential for secondary impacts of the pole with the roof of the test vehicle as observed in the low-speed test of the 13.7-m (45-ft) pole. A successful low-speed test of the 12.2-m (40-ft) system would indicate that ADOT's standard poles which are 12.2-m (40-ft) or less in height satisfy the impact criteria of NCHRP Report 350.

Test 472360-3 (Low-Speed Test)

The test vehicle, shown in Figure 30, was a 1988 Subaru Justy. Test inertia weight of the vehicle was 820 kg (1,808 lb) and its gross static weight was 895 kg (1,973 lb). The height to the lower edge of the vehicle bumper was 340 mm (13.4 in) and the height to the top of the

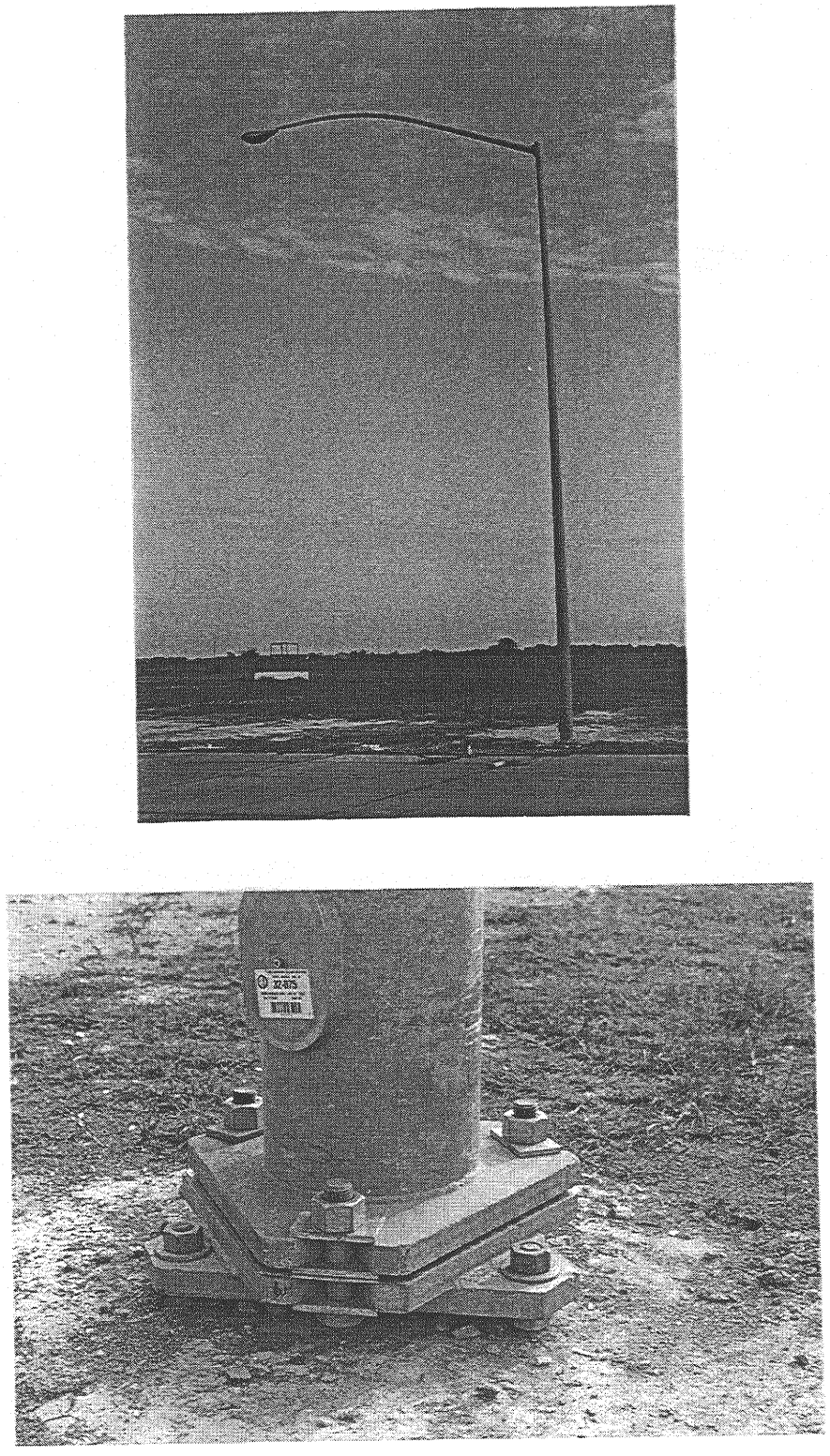


Figure 29. 12.2-m (40-ft) Arizona slip-away base luminaire support.

Figure 30. Vehicle prior to test 472360-3.

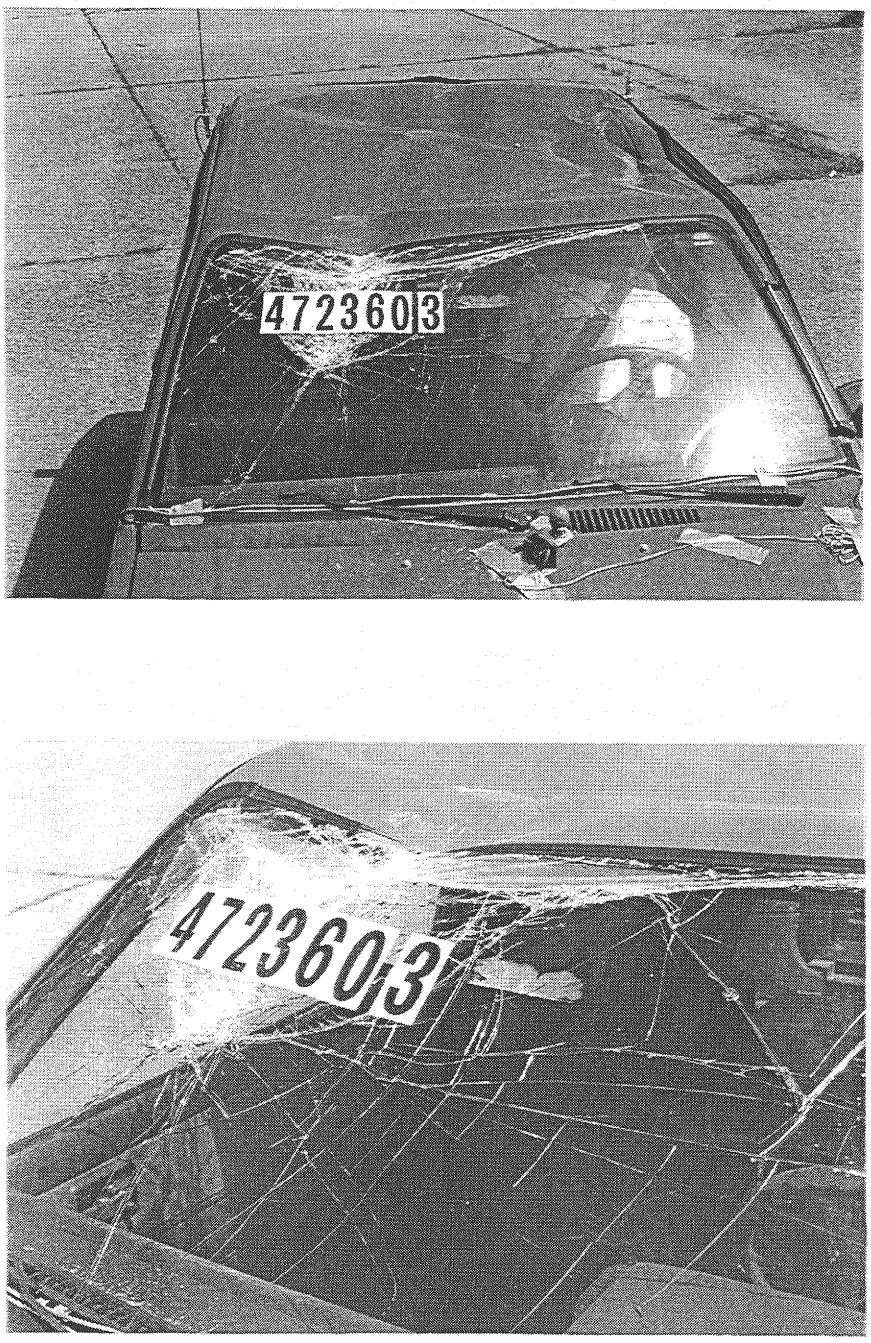


Figure 36. Damage sustained to roof of vehicle (test 472360-3).

bumper was 500 mm (19.7 in). The position of the vehicle relative to the luminaire pole is shown in Figure 31. Additional dimensions and information pertaining to the test vehicle are given in Figure 32. The vehicle was directed into the guardrail system using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact.

The vehicle impacted the luminaire support, with the centerline of the vehicle aligned with the centerline of the support, at a speed of 35.7 km/h (22.2 mi/h) and a zero degree heading angle. Upon impact, the slip base activated readily and the base of the pole was propelled upward and forward of the test vehicle. At the time the vehicle initially lost contact with the luminaire support, the angular velocity of the pole was 62.3 deg/sec. The luminaire support continued to translate forward and rotate over the vehicle, eventually recontacting the front of the vehicle about 1.114 s after the initial impact. As the pole continued to fall, it contacted the front edge of the roof and rolled across the top of the vehicle, raising the base of the pole into the air above the vehicle. The pole base plate subsequently contacted the roof of the vehicle, causing substantial deformation to the left front quarter of the roof. Shortly thereafter, the luminaire support lost contact with the roof, with the vehicle traveling at a speed of 10.8 km/h (6.7 mi/h). The brakes were applied, and the vehicle skidded to rest approximately 16.4 m (53.8 ft) downstream and 0.6 m (2.0 ft) right of the initial point of impact. The luminaire support continued to rotate until the top end of the pole impacted the roadway surface approximately 1.722 s after impact. Sequential photographs of the impact are shown in Figure 33.

The post-test positions of the luminaire support and test vehicle are shown in Figure 34. With the exception of the luminaire, which released from the mast arm and shattered on the ground, the luminaire support was essentially undamaged. Exterior body damage sustained by the vehicle is shown in Figure 35. The vehicle received a maximum crush of 55 mm (2.2 in) at the front center of the vehicle and 120 mm (4.7 in) on the roof. There was also damage to the front bumper, grill, hood, windshield, and rear hatch. Damage to the roof is shown in Figure 36.

Data from the accelerometer located at the center-of-gravity were digitized for evaluation of occupant risk and were computed as follows. In the longitudinal direction, occupant impact velocity was 2.8 m/s (9.3 ft/s) at 0.280 s, the highest 0.010-s average ridedown acceleration was -2.4 g between 0.523 and 0.533 s, and the maximum 0.050-s average acceleration was -4.6 g

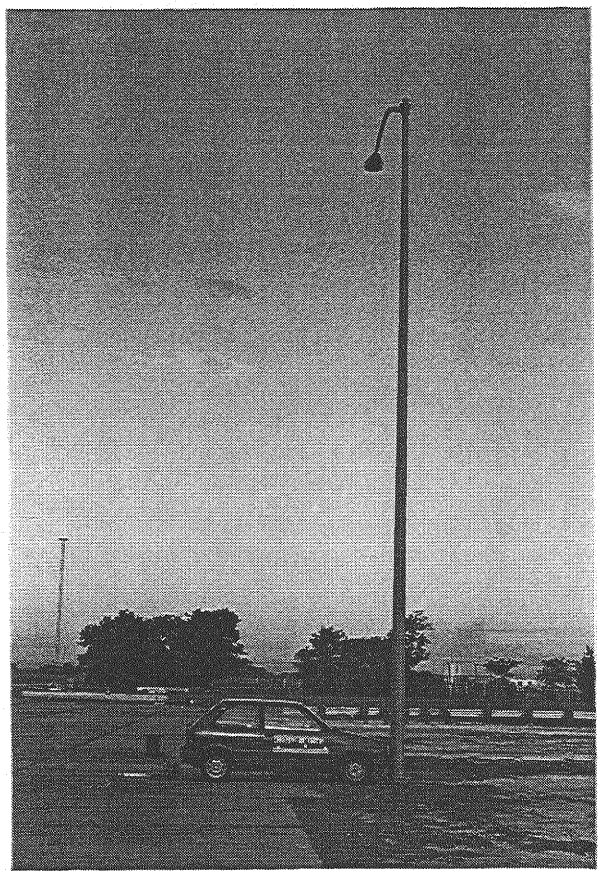


Figure 31. Vehicle/test installation geometrics for test 472360-3.

DATE: 4-18-94 TEST NO.: 472360-3 VIN NO.: 1F1KA73A31B703560 MAKE: Subaru

MODEL: Justy YEAR: 1988 ODOMETER: 09866 TIRE SIZE: 155R12

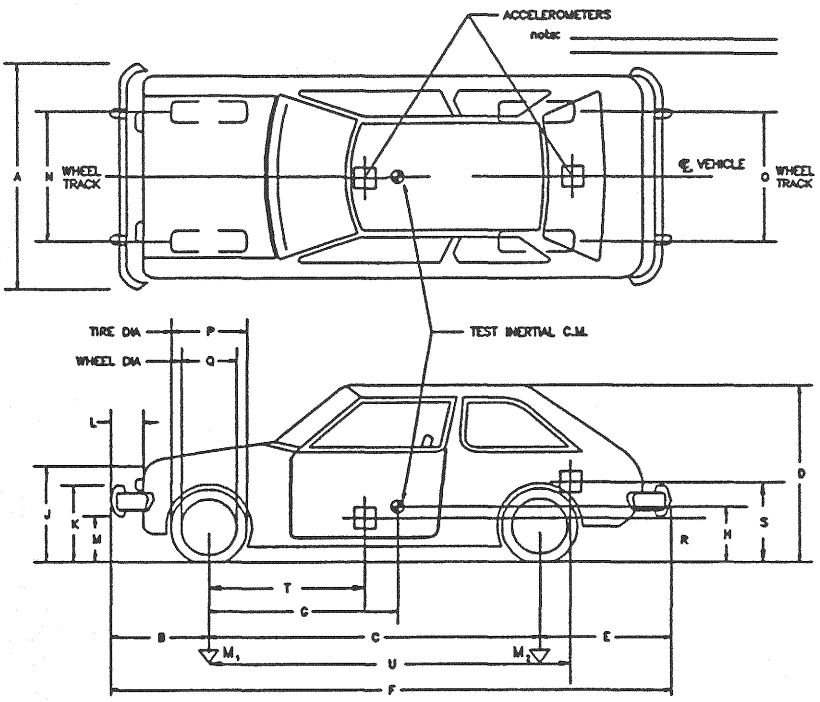
TIRE INFLATION PRESSURE: _____

MASS DISTRIBUTION (kg) LF 249 RF 255 LR 164 RR 152

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:

_____

_____



ENGINE TYPE: 3 cyl Gas,

ENGINE CID: 73

TRANSMISSION TYPE:

X AUTO

_ MANUAL

OPTIONAL EQUIPMENT:

_____

_____

_____

DUMMY DATA:

TYPE: _____

MASS: _____

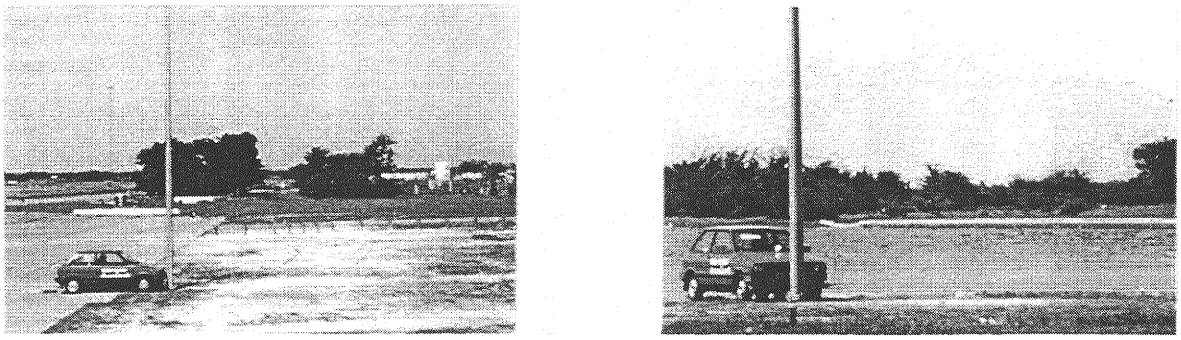
SEAT POSITION: _____

GEOMETRY – (mm)

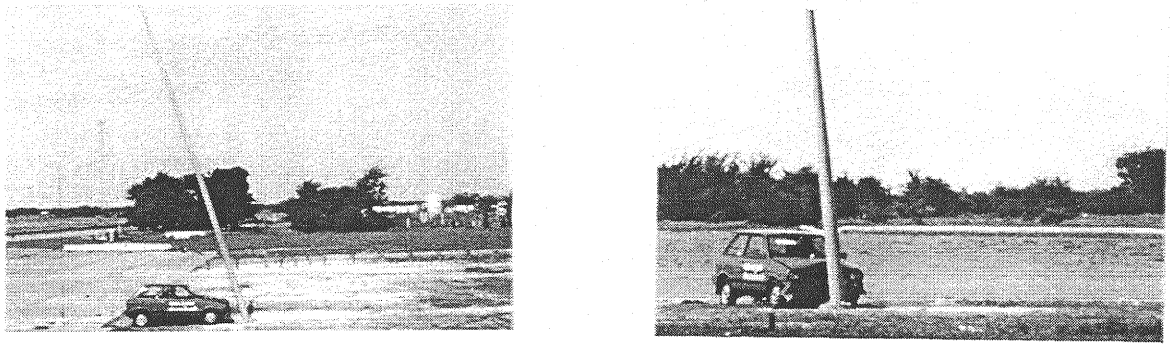
A	1500	E	590	J	730	N	1330	R	430
B	610	F	3500	K	500	O	1300	S	725
C	2300	G		L	500	P	550	T	830
D	1360	H		M	340	Q	-30	U	2590

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	484	504	545
M_2	274	316	350
M_T	758	820	895

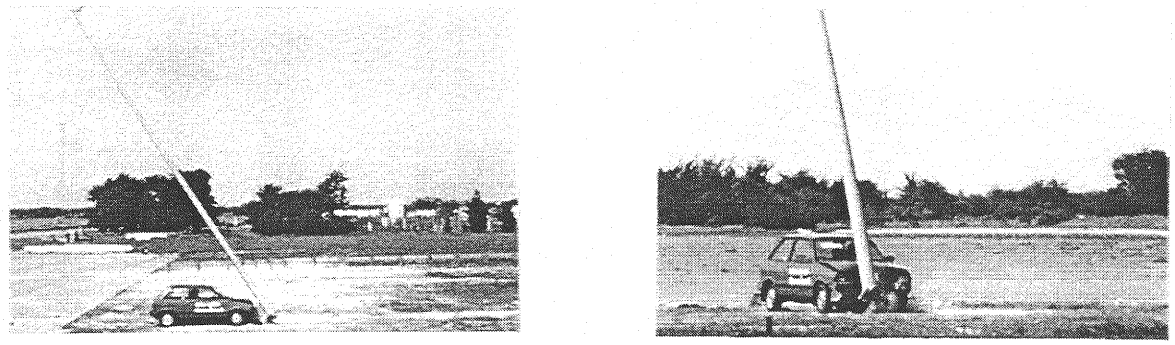
Figure 32. Vehicle properties for test 472360-3.



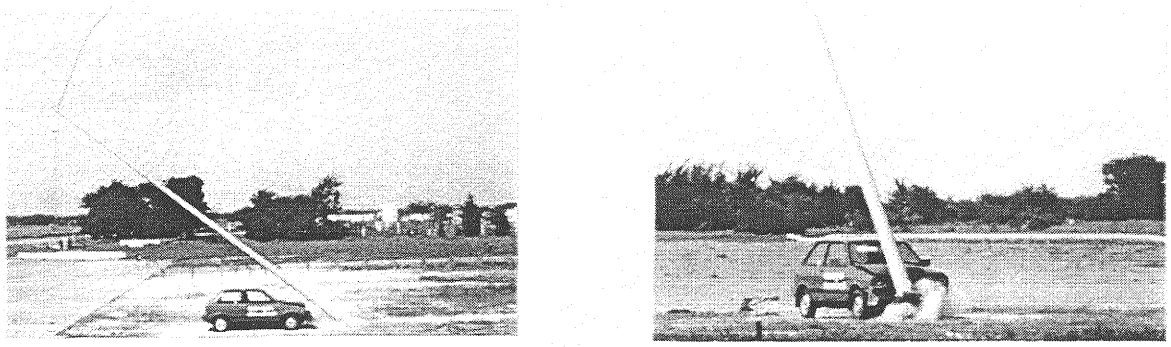
0.000 s



0.332 s

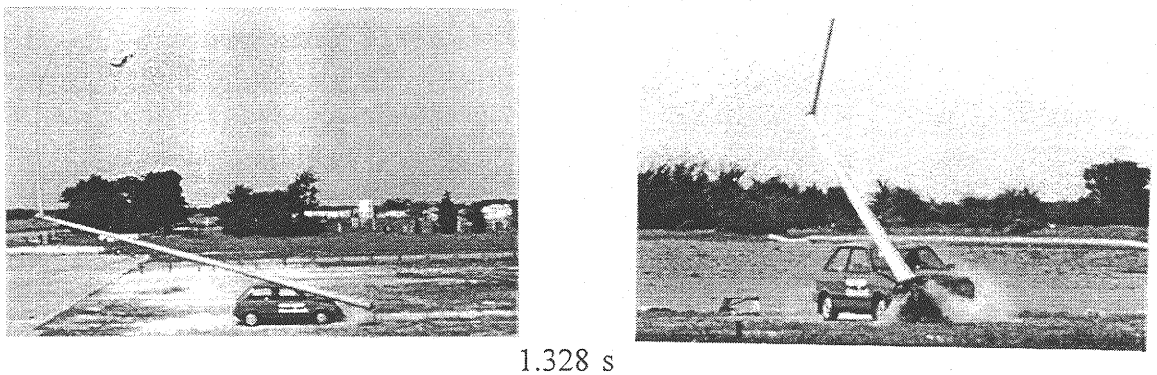


0.664 s

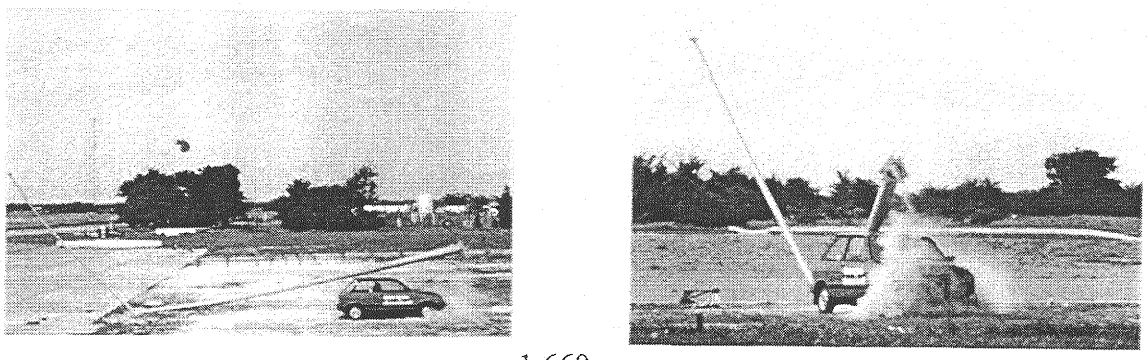


0.996 s

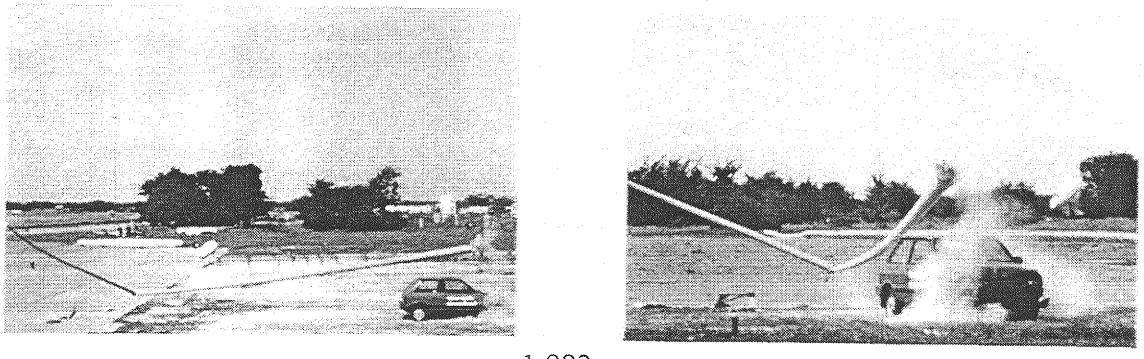
Figure 33. Sequential photographs for test 472360-3.
(perpendicular and downstream angular views)



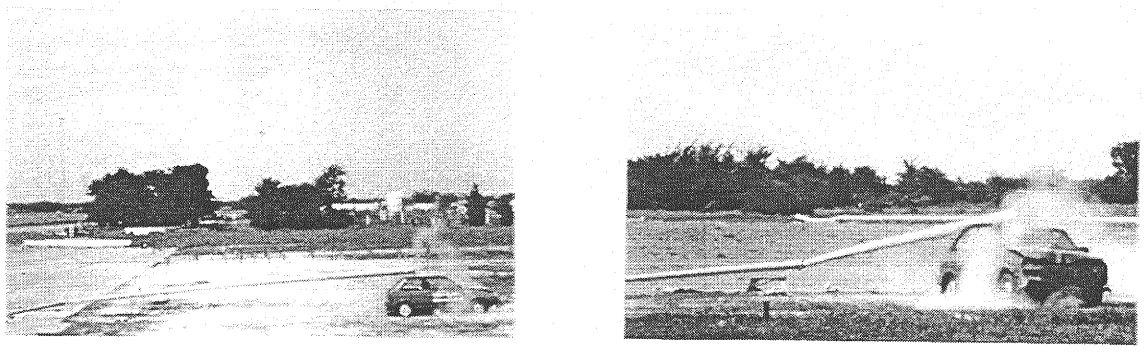
1.328 s



1.660 s



1.993 s



2.325 s

Figure 33. Sequential photographs for test 472360-3 (continued).
(perpendicular and downstream angular views)

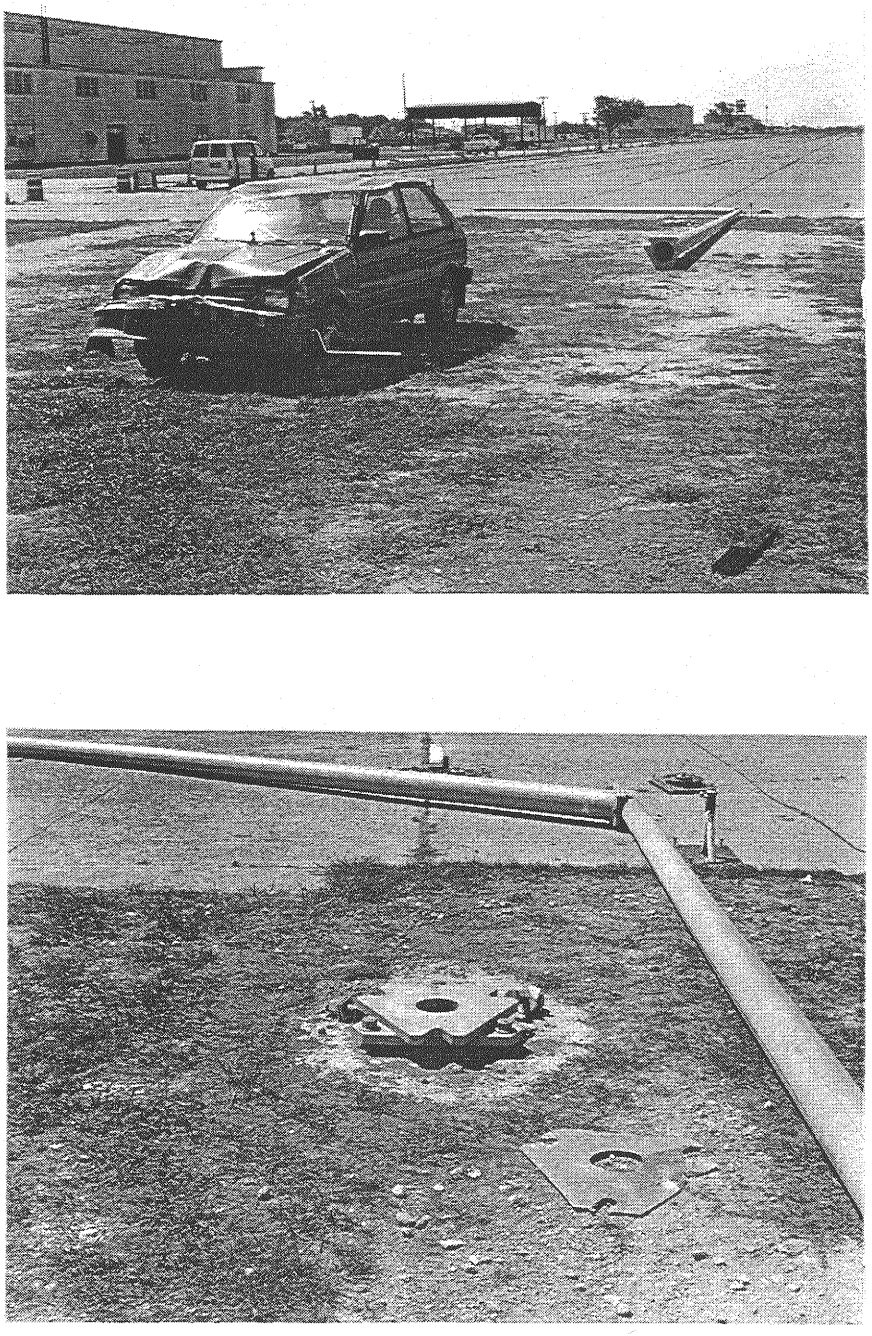


Figure 34. Slip-away base luminaire support installation after test 472360-3.

Figure 35. Vehicle after test 472360-3.

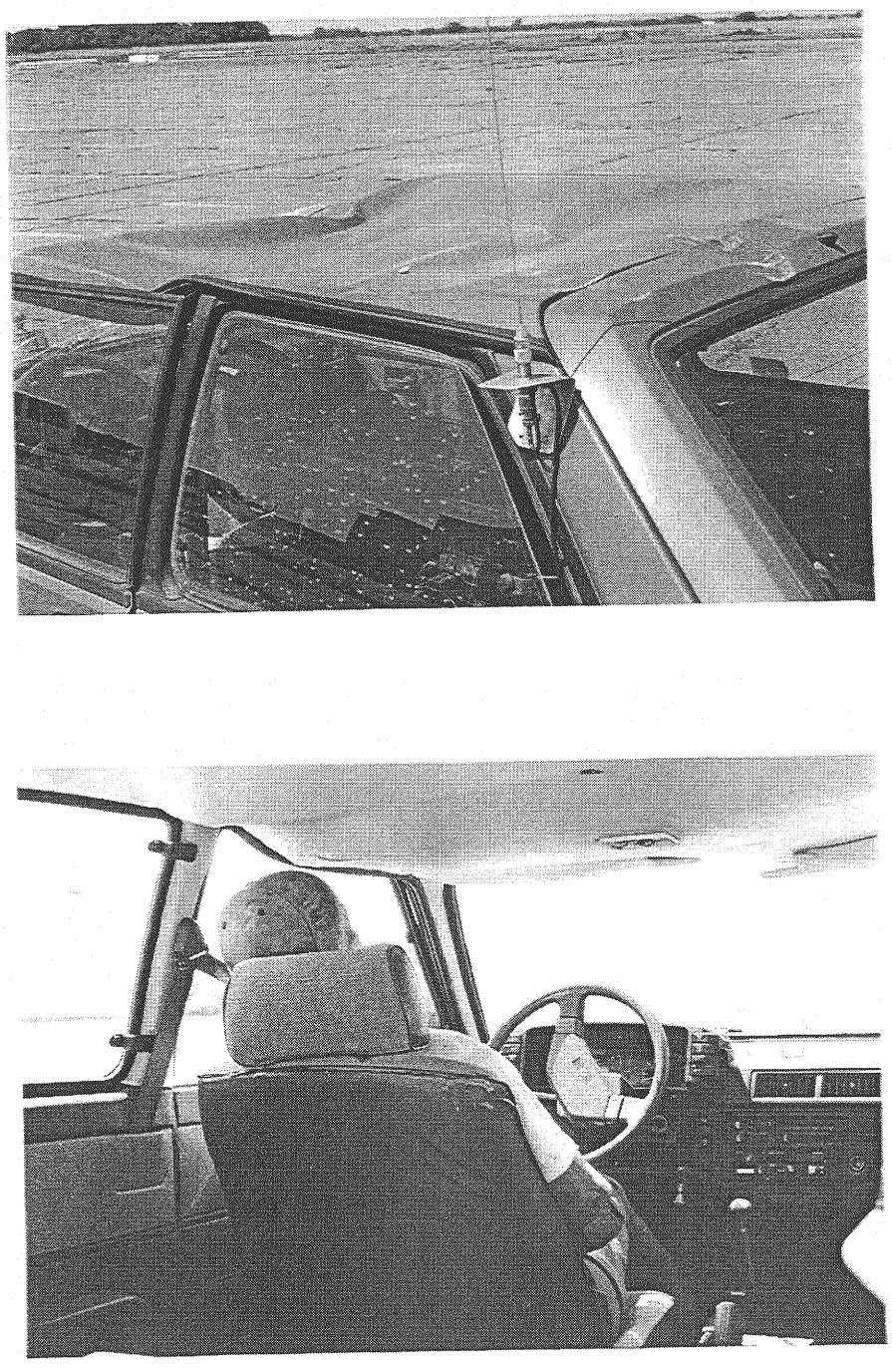


Figure 36. Damage sustained to roof of vehicle (continued).

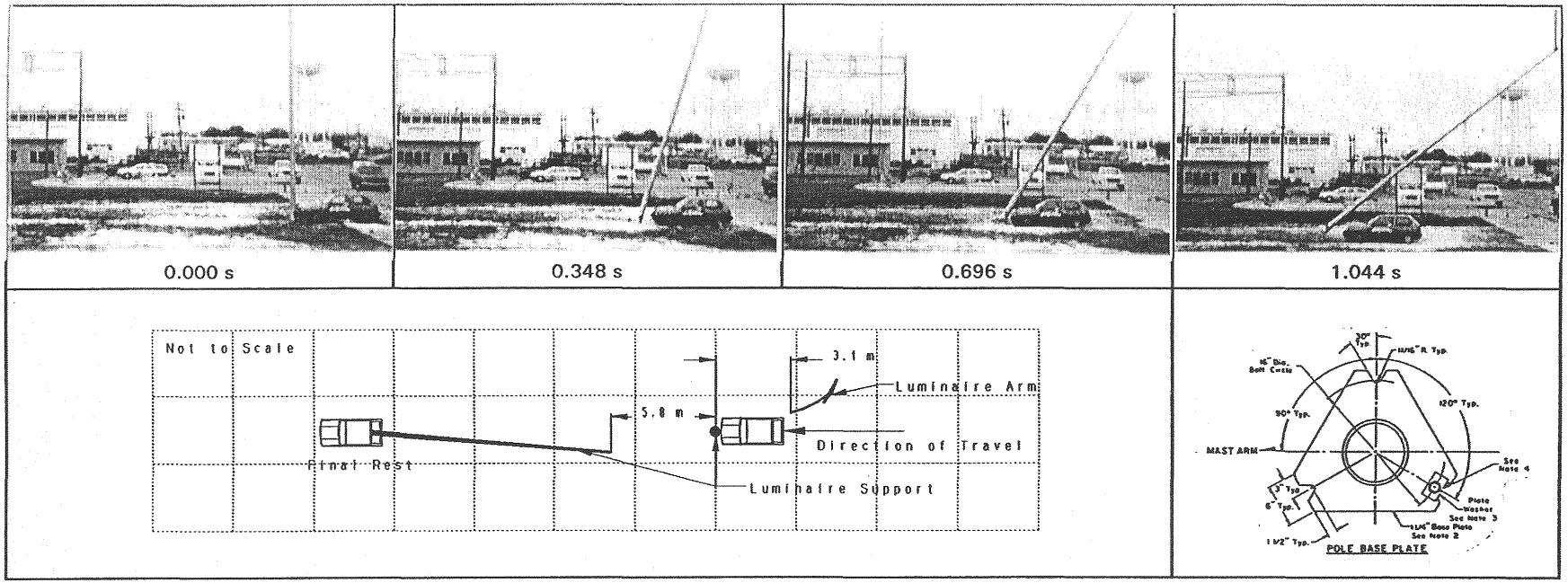
between 0.005 and 0.054 s. In the lateral direction, occupant impact velocity was -0.3 m/s (-0.8 ft/s) at 0.280 s, the highest 0.010-s occupant ridedown acceleration was -0.6 g between 0.526 and 0.536 s and the maximum 0.050-s average acceleration was -0.3 g between 0.078 and 0.128 s. These data and other pertinent information from the test are summarized in Figure 37. Vehicular angular displacements are displayed in Figure 38. Vehicular accelerations versus time traces filtered digitally at 60 Hz are presented in Figures 39 through 41. An *NCHRP Report 350* evaluation summary of test 472360-3 is shown in Table 4.

In summary, the luminaire support readily yielded to the vehicle. The occupant impact velocities and ridedown accelerations were well within the recommended limits established by *NCHRP Report 350*, and the test vehicle remained upright and stable both during and after the impact event. However, the test vehicle sustained substantial deformation to the roof structure from a secondary impact with the luminaire pole. The maximum recorded crush was 120 mm (4.7 in). Although this value is significantly less than that observed in the test of the 13.7-m (45-ft) luminaire support (test 472360-2), it is nonetheless a cause for concern. After careful review of previous test data, and the location and extent of deformation to the roof, the test was judged to be marginally acceptable.

Discussion

After receiving approval from the Project Manager, information pertaining to the luminaire test program was submitted to the Federal Highway Administration for review. After reviewing the performance of ADOT's 13.7-m (45-ft) luminaire pole and other breakaway support structures, FHWA concurred with the researchers opinion that the roof crush and associated intrusion into the occupant compartment of the vehicle was significant enough to be considered unacceptable. It was noted that some previous tests of breakaway sign and luminaire supports resulting in localized roof crush in the range of 100 to 150 mm (3.9 to 5.9 in.) have been considered acceptable. However, in the test of the 13.7-m (45-ft) system, not only did the magnitude of the roof crush exceed this range, but the extent of damage was severe across the entire roof of the vehicle.

In a similar review of the test conducted on the 12.2-m (40-ft) luminaire support, FHWA concurred with the researchers that the system was acceptable. The maximum roof crush of



General Information	
Test Agency	Texas Transportation Institute
Test No.	472360-2
Date	03/25/94
Test Article	
Type	Luminaire Support
Name or Manufacturer	Arizona Slip-away base
Installation Length (m)	13.7 m (45.0 ft)
Size and/or dimension and material of key elements	steel pole
Soil Type and Condition	Concrete Footing
Test Vehicle	
Type	Production Model
Designation	820 C
Model	1988 Chevrolet Sprint
Mass (kg) Curb	719
Test Inertial	820 (1,808 lb)
Dummy	75 (165 lb)
Gross Static	896 (1,975 lb)

Impact Conditions	
Speed (km/h)	35.8(22.2 mi/h)
Angle (deg)	0
Exit Conditions	
Speed (km/h)	23.0(14.3 mi/h)
Angle (deg)	N.A.
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	2.6 (8.6 ft/s)
y-direction	-0.3 (-1.0 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-3.2
y-direction	1.5
PHD (optional)	
ASI (optional)	
Max. 0.050-sec Averages (g's)	
x-direction	-4.7
y-direction	0.7
z-direction	-1.2

Test Article Deflections (m)	
Dynamic	N.A.
Permanent	N.A.
Vehicle Damage	
Exterior	
VDS	12FC-2
CDC	12FCEKI & 12TZCN3
Interior	
OCDI	AS0300000
Maximum Exterior Vehicle Crush (mm)	200 (7.9 in)
Max. Occ. Compart. Deformation (mm)	203 (8.0 in)
Post-Impact Behavior	
Max. Roll Angle (deg)	-2.0
Max. Pitch Angle (deg)	-2.2
Max. Yaw Angle (deg)	4.1

Figure 37. Summary of results for test 472360-2.

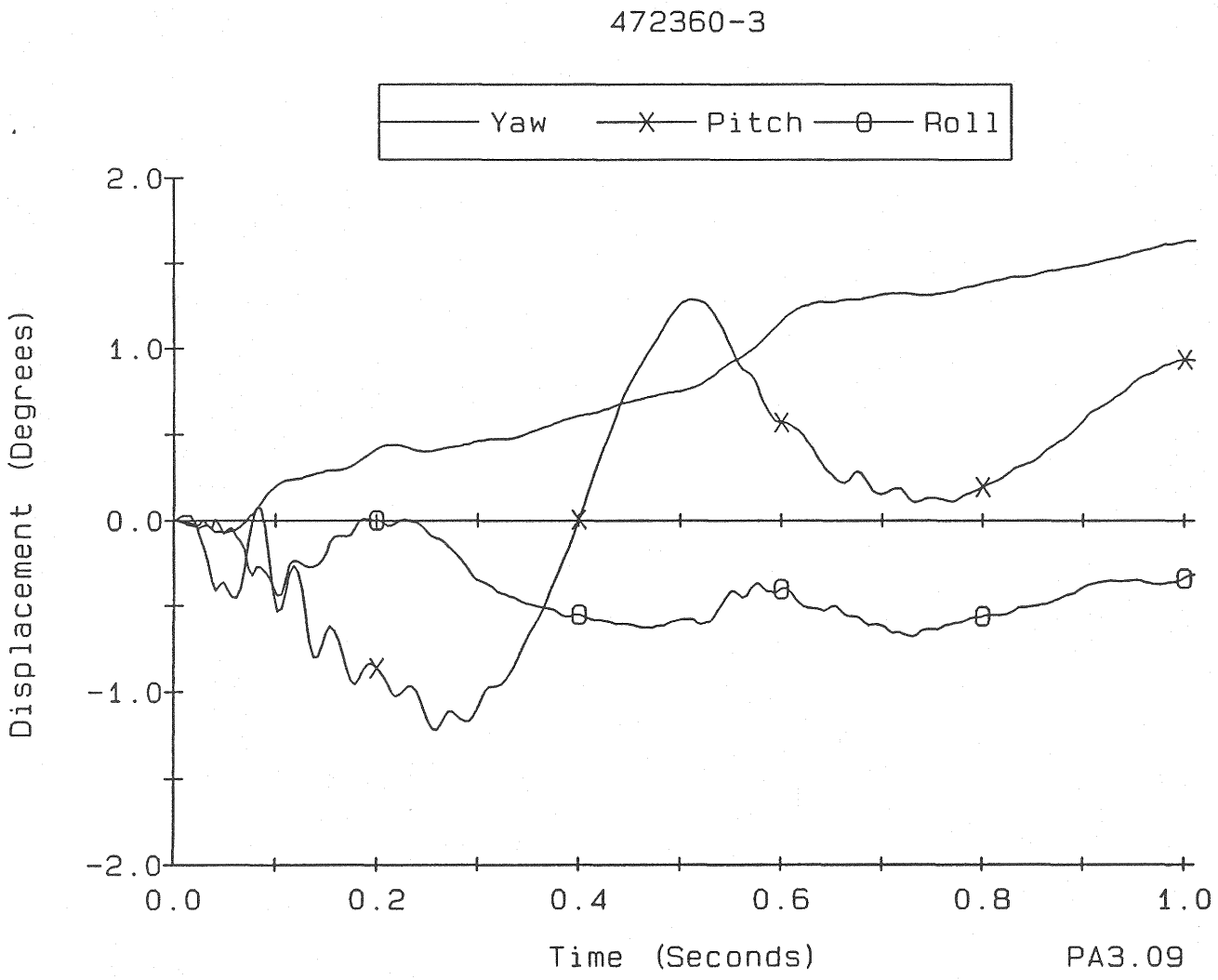


Figure 38. Vehicle angular displacements during test 472360-3.

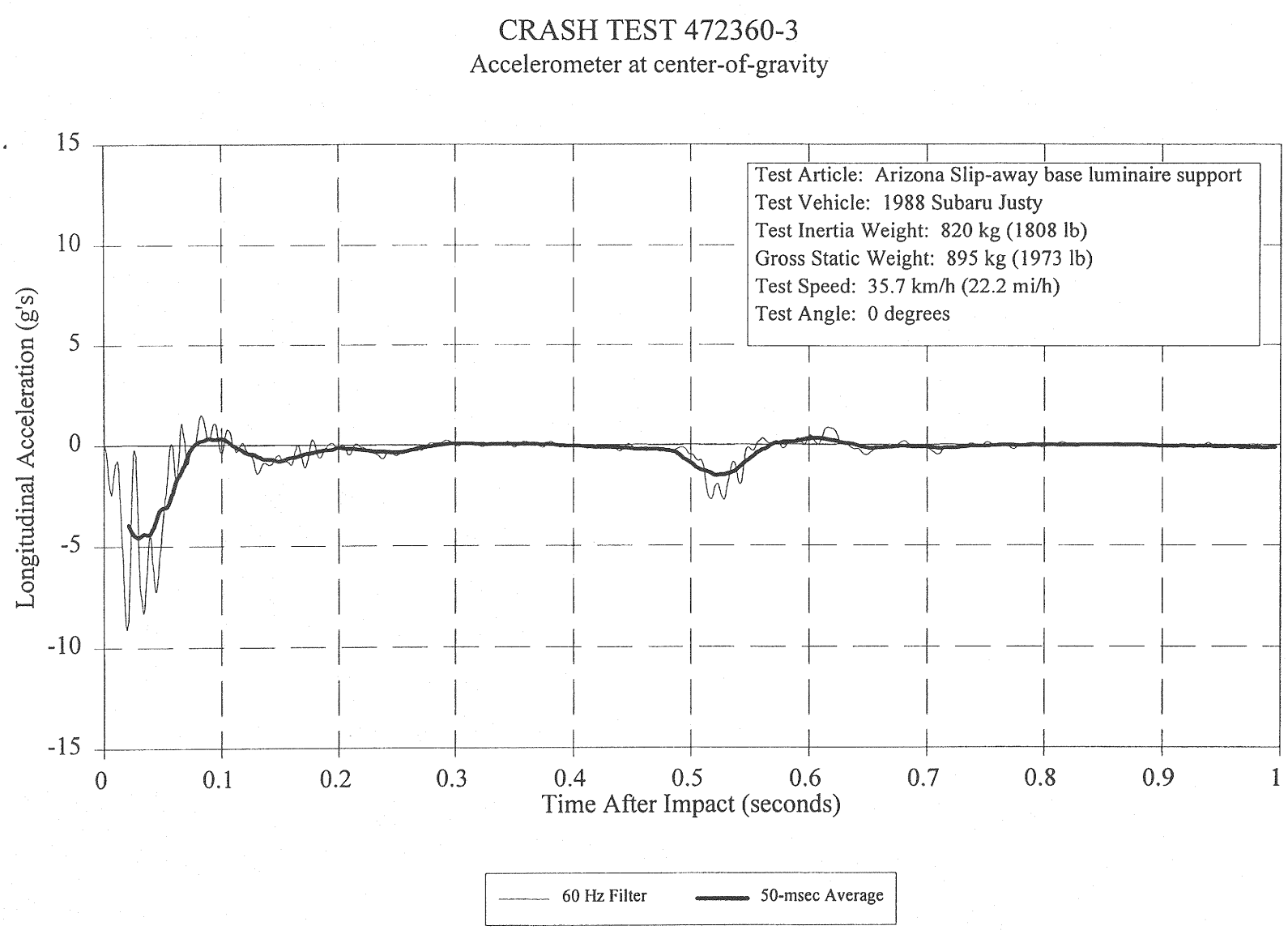


Figure 39. Vehicle longitudinal accelerometer trace for test 472360-3.

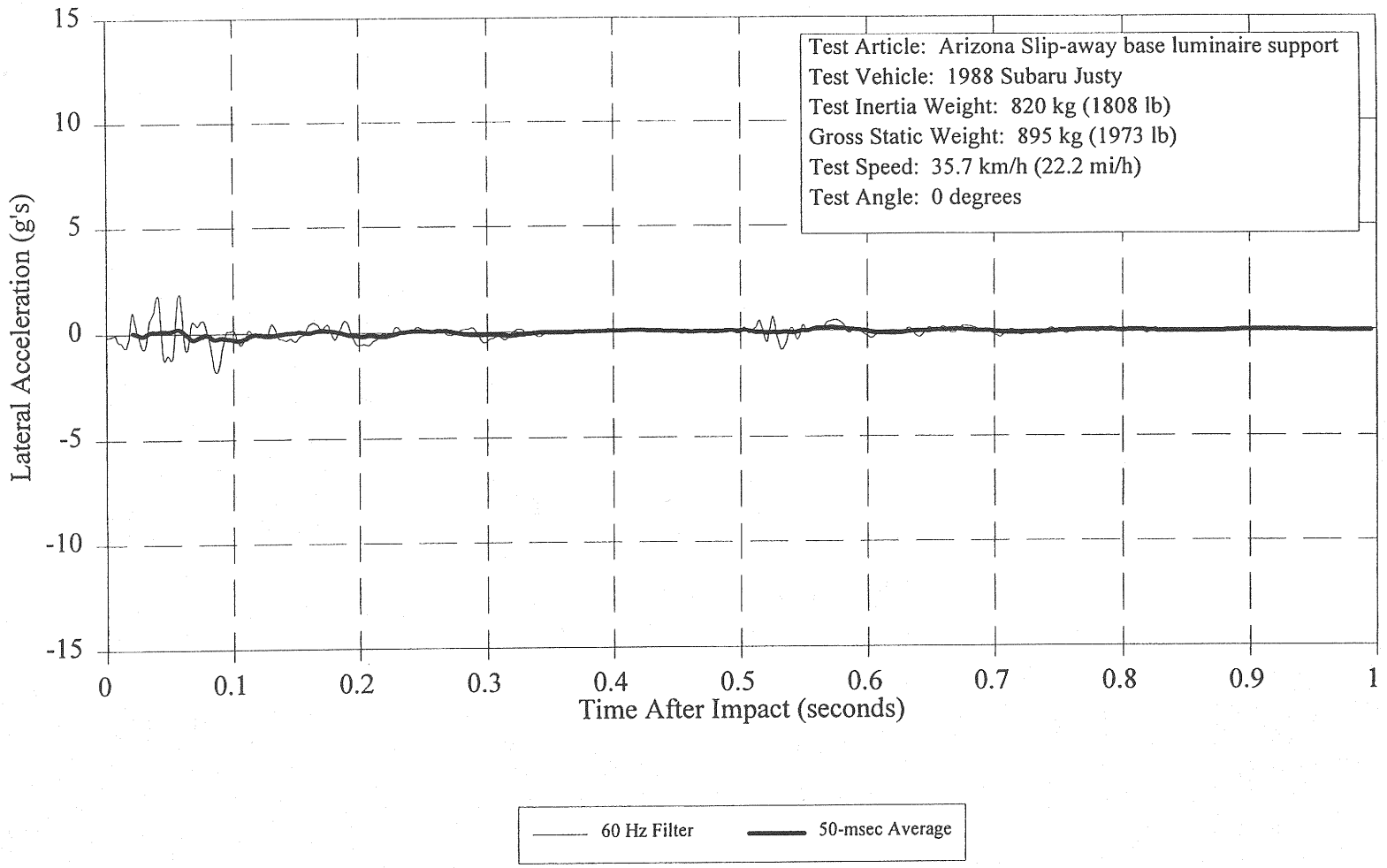


Figure 40. Vehicle lateral accelerometer trace for test 472360-3.

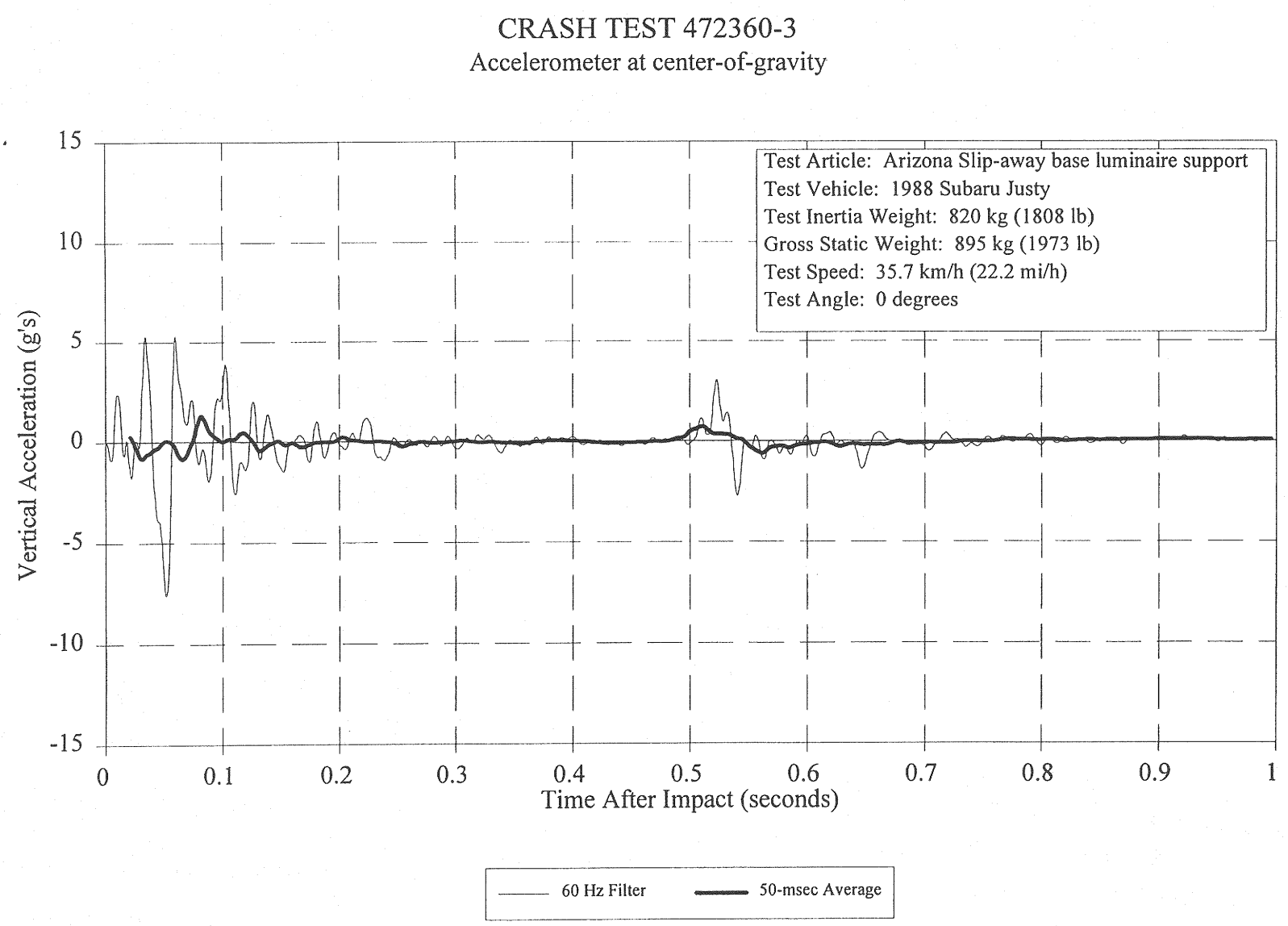


Figure 41. Vehicle vertical accelerometer trace for test 472360-3.

Table 4. Summary of NCHRP Report 350 evaluation criteria for test 72360-3

Test No.: 472360-3 Test Date: 04/18/94 Test Agency: Texas Transportation Institute

Evaluation Criteria	Test Results	Assessment
Structural Adequacy B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.	The luminaire support yielded by disengaging the slip-plate bolts attaching the mating surfaces of the slip-away base plates.	Pass
Occupant Risk D. Detached elements should not penetrate the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of the occupant compartment that could cause serious injuries should not be permitted.	The luminaire detached from the mast arm but **did not** present a hazard to other travel lanes. There **was** deformation of the roof structure, but it was judged to be of an acceptable nature.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright and stable throughout the test period.	Pass
H. Occupant impact velocities should satisfy the following: Occupant Impact Velocity Limits (m/s) Component / Preferred / Maximum Longitudinal and Lateral / 9 / 12	Longitudinal occupant impact velocity: 2.8 m/s (9.3 ft/s) Lateral occupant impact velocity: 0.3 m/s (0.8 ft/s)	Pass
I. Occupant ridedown accelerations should satisfy the following Occupant Ridedown Acceleration Limits (G's) Component / Preferred / Maximum Longitudinal and Lateral / 15 / 20	Longitudinal Occupant Ridedown Acceleration: -2.4 g's Lateral Occupant Ridedown Acceleration: -0.6 g's	Pass
Vehicle Trajectory K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle trajectory was judged to be acceptable.	Pass

120 mm (4.7 in.) was within the acceptable range as defined by previously accepted systems, and the extent of damage was much more localized than in the previous test of the 13.7-m (45-ft) system. A copy of the response letter from FHWA which cites these opinions is included as Appendix A of this report.

The results of these tests raised some fundamental concerns regarding the acceptable weight limit for luminaire systems. It was thought that the 453.6 kg (1,000 lb) limit set forth in the July 6, 1990 FHWA memorandum, "Breakaway Sign and Luminaire Supports" (4), was within the range that would not cause unacceptable damage should the pole fall directly onto the impacting vehicle. In light of the results of these tests, FHWA is considering revising the acceptable limit for the mass of a support to 375 kg (827 lb), which is approximately the mass of the 12.2-m (40-ft) luminaire system used in test 472360-3. An August 19, 1994 memorandum entitled "Breakaway Luminaire Supports" was sent to regional Federal Highway Administrators to determine the extent of the luminaire support problem and the impact that a change in the acceptable support mass to 375 kg (827 lb) would have on State highway agencies. A copy of this memorandum is attached as Appendix B of this report.

ACCEPTABLE SLIP-BASE LUMINAIRE SYSTEMS

As discussed in the preceding section, ADOT's standard 13.7-m (45-ft) constant tapered luminaire pole was found to be deficient when tested in accordance with the impact performance guidelines contained in *NCHRP Report 350*. It can also be inferred from this testing that the other 45-ft pole designs, which weigh more than the constant tapered design which was tested, would also exhibit unacceptable behavior.

In light of this deficiency, a significant amount of effort was directed toward identifying approved, crashworthy luminaire systems which provide a mounting height of 13.7 m (45 ft) or greater and which could serve as replacements for ADOT's current 13.7-m (45-ft) poles. When this issue was addressed to the project's technical panel, there were no restrictions placed on the type of breakaway mechanism or pole that should be considered. In other words, although it would be desirable to identify a steel pole slip-base system similar to those currently in use by ADOT, consideration would also be given to alternate breakaway mechanisms (e.g. cast aluminum shoe and transformer bases, aluminum and cast iron couplings, extruded aluminum bases, and direct burial fiberglass) and pole types (e.g. aluminum, fiberglass, high-strength steel).

Telephone interviews were made with selected state transportation agencies, the Federal Highway Administration, and various pole manufacturers to aid in this identification process. Although several state transportation agencies were identified as having slip-base mounted luminaire supports, many of these systems either did not satisfy the necessary mounting height requirement or had not been crash tested. Some of these systems were approved for use based on the fact that they satisfy the weight requirements and other provisions for the use of steel slip-base luminaire supports as presented in the July 6, 1990 FHWA memorandum on the subject (4). However, as shown in the test program conducted under this study, agreement with this provisions does not necessarily provide assurance that the luminaire system will meet current impact performance guidelines. In fact, as mentioned previously, FHWA is considering a reduction in the allowable luminaire support mass in response to the poor performance of ADOT's 13.7-m (45-ft) luminaire system which weighed slightly less than the current acceptable weight limit of 453 kg (1,000 lb). If the proposed weight limit of 375 kg (827 lb) is adopted,

it may necessitate the testing of these heavier poles to permit their continued use. A copy of the FHWA memorandum addressing this issue is attached as Appendix B of this report.

For this reason, the effort of identifying suitable replacements for ADOT's 13.7-m (45-ft) poles focused on systems which have been approved by FHWA on the basis of full-scale crash tests, bogie vehicle tests, or, at a minimum, pendulum tests. One system that shows great promise in this regard is a steel 4-bolt slip-base luminaire support system that was developed by the Utah Department of Transportation (UDOT) (6). When subjected to full-scale crash testing, this system exhibited acceptable impact performance for both the high-speed and low-speed tests. Although the pole rolled across the roof of the test vehicle in the low-speed test, it only produced an estimated 25 to 40 mm (1 to 1.6 in.) of roof crush. The system had a total weight of 410 kg (902 lb) and consisted of a tapered 15.2-m (50-ft) pole with an 11-ga. wall thickness. The tested configuration consisted of dual 4.6-m (15-ft) mast arms and simulated luminaires which provided a nominal mounting height of 15.8 m (52 ft). This system is currently being used in the states of Utah, Montana, Idaho, Wyoming, and Nevada. It was approved by FHWA (Roadside and Geometric Design Acceptance Letter LS-25) for luminaire mounting heights up to 17.25 m (56.5 ft).

Valmont Industries received approval for use of a steel slip-base luminaire system based on bogie vehicle tests conducted at the Federal Outdoor Impact Laboratory (FOIL). In this program, a high-speed and low-speed test were conducted on a 437-kg (964-lb) support which had a pole shaft length of 14.8 m (48.5 ft) and a mounting height of 16.9 m (55.5 ft). The approval of the systems was based on the fact that the slip-base activated readily and the occupant impact velocities were within acceptable values. In fact, these tests were the primary basis upon which the 454 kg (1,000 lb) weight limit was established. However, because the testing was conducted with a bogie vehicle without a compliant roof structure, the extent of roof crush could not be evaluated. It is the authors' opinion that when pole trajectory is considered, this system may not meet current impact performance guidelines.

Most of the other FHWA approved systems are also associated with various pole manufacturer and suppliers, and primarily consist of cast aluminum transformer or shoe bases and various proprietary breakaway coupling mechanisms. Several of these approved systems have mounting heights of 13.7 m (45-ft) or greater and, thus, may be suitable candidates for the

replacement of ADOT's 13.7-m (45-ft) pole. Table 5 lists some of the relevant parameters of several luminaire systems which are offered for consideration.

Table 5. Approved Luminaire Systems with Mounting Heights Greater Than 13.7 m (45-ft)

FHWA Approval Letter	Manufacturer	Breakaway Mechanism	Support Type	Luminaire Mast Arm		Luminaire Mounting Height m (ft)	Weight kg (lb)
				Single or Dual	Length m (ft)		
LS-2	Akron Foundry	Cast Al Transformer Base (TB1-AF)	Steel			15.2 (50)	232 (511)
"	"	"	Aluminum			15.5 (51)	353 (778)
LS-3	Union Metal	Cast Al Shoe Base	Aluminum			15.2 (50)	184 (405)
LS-5	Hapco	Impact Safety Coupling	Aluminum			17.7 (54)	252 (556)
LS-7	Shakespeare Products	TranspoSafety Coupling	Fiberglass			13.7 (45)	201 (444)
LS-8	Transpo Industries	Pole-Safe Breakaway Coupling	various			16.8 (55)	407 (897)
LS-10	PrecisionForm	Frangible Coupler	Aluminum			16.2 (53)	237 (523)
LS-13	P&K Pole Products	Aluminum Slip Base	Aluminum			15.2 (50)	249 (548)
LS-17	Akron Foundry	CS-370 Al Transformer Base (Feralux Base)	Steel	D	4.6 (15)	16.7 (54.75)	433 (955)
"	"	"	Aluminum	D	4.2 (13.7)	15.2 (50)	268 (591)
LS-18	"	F-1302 Al Transformer Base (Pole Lite Base)	Steel	D	4.6 (15)	16.7 (54.75)	433 (955)
"	"	"	Aluminum	D	4.2 (13.7)	15.2 (50)	268 (591)
LS-28	Adian Engineering	Adian Breakaway Base (proprietary)	Aluminum			15.2 (50)	242 (531)
LS-29	Hapco	Extruded Aluminum Base	Aluminum			16.8 (55)	250 (550)
LS-33	Manitoba Safe-T-Base	Cast Iron Breakaway Coupling				13.7 (45)	250 (550)
LS -34	Millerbernd Manufacturing	Progressive Shear Base	Carbon Steel		2.7- 3.7 (9-12)	15.6 (51)	177 (390)

In addition to the various breakaway mechanisms listed above, the feasibility of direct burial fiberglass supports was also investigated. Although fiberglass poles with mounting heights of up to 11.3 m (37 ft) have been successfully tested for Shakespeare Products and Sherman International, there are currently no such systems which provide mounting heights in the range required by ADOT. A complete listing of FHWA approval letters for luminaire supports is presented in Appendix C.

It should be noted that the FHWA acceptance is based on the safety performance and breakaway characteristics of the systems and does not address structural adequacy. Should ADOT elect to examine one or more of these systems in greater detail, a structural analysis should be performed for the applicable dead loads and wind loads to which the structure is subjected.

An alternative to adopting a new design may be to decrease the weight of the existing 13.7-m (45-ft) designs to acceptable levels through redesign of the luminaire system. For instance, it may be feasible to utilize a high-strength steel pole with a smaller wall thickness to achieve a reduction in weight. If the 6.1-m (20-ft) mast arm is not frequently used, an additional option would be to reduce the length of the maximum acceptable mast arm and, thereby, reduce the structural requirements of the luminaire pole. Another means of achieving a reduction in total mass through redesign is by lowering the wind load requirements from those resulting from using 25 or 50-year return frequency isotachs, to those resulting from 15-year isotachs. Such a measure is being proposed by FHWA as a means of reducing the weight of existing luminaire systems (see Appendix B).

It should also be noted that it is often the deflection requirements imposed on a luminaire structure, rather than the strength requirements, which control the design. This is almost certainly the case for a large 6.1-m (20-ft) mast arm such as those used by ADOT. If the length and/or weight of the luminaire arm could be reduced, or some amount of deflection be tolerated, the weight of the luminaire pole could be reduced. The acceptable static deflection of a single mast arm luminaire pole is primarily an issue of aesthetics, and can likely be increased without compromising the strength of the support.

Finally, the authors have recently been awarded an FHWA grant to examine the luminaire problem through the use of sophisticated finite element vehicle and pole models (7). The effect of variables such as mass distribution will be investigated to learn more about the behavior of

luminaire poles during impacts. Hopefully the insight gained from this study will permit improved luminaire designs and indicate critical factors in the proper safety performance of these structures.

SLIP-BASE BOLT TORQUES

Background

Certain conditions must be met for proper actuation of the slip-base support system. First, there are limits to the poles's mass; if the pole is too massive, or if the mass is concentrated too close to the base, proper actuation and hence acceptable impact performance may not be achieved. These conditions must be controlled in the pole's design. Second, the slip-base hardware must be designed properly, including the slip-base plates and their slotted and flared holes, and the nuts, bolts, washers, and keeper plate. Third, the bolts/nuts must be torqued to meet wind, ice, and dead load demands; however, excessive bolt torque may result in unacceptable breakaway performance. Fourth, the height of the lower slip-base plate above the terrain adjacent to the base of the pole must be in conformance with specifications given in the 1990 AASHTO "Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals" (5), and the interim specifications published in 1994 (8). Finally, debris, soil, corrosion, erosion, or other hindrances that could compromise proper actuation of the slip-base must be avoided. This section addresses bolt torque issues.

One of the factors affecting the performance of a slip-base breakaway system is the force required to initiate sliding or movement of the upper slip base. If the inertia of the pole is disregarded, the force required to initiate movement is a function of the net clamping force holding the upper and lower slip plates together. The primary indicator normally used to estimate the clamping force is the torque in each of the slip bolts holding the slip plates together. It has been shown that bolt tension, and hence clamping force, is proportional to the torque used to tighten the bolt. If the torque, and hence the clamping force, is too large the slip base may not actuate properly.

Telephone interviews were made with selected state transportation agencies across the USA, Federal Highway Administration engineers in Washington, D.C., and with pole suppliers to determine if they had inspection and maintenance procedures relative to bolt torques for slip-base breakaway light poles, or if they were aware of other agencies that had such procedures. Apparently there are no such procedures being used in any of the states.

As a result of catastrophic failures, Michigan DOT has recently developed installation and inspection procedures and specifications for anchor bolts on large, rigid cantilevered sign supports, a copy of which is given in Appendix D. Although some of the guidance contained therein may have application, for the most part they are not applicable to slip-base light pole supports.

Recommended Torque Values

According to FHWA guidelines (4), the clamping force (tensile load) per bolt in a three-bolt slip-base system should not exceed 8,000 lb, or a net 24,000 lb for all three bolts. While it is desirable to have a uniform tensile load in each of the three slip bolts, the primary intent is that the net load not exceed 24,000 lb. For the 1¼ in. bolts used in the ADOT poles, FHWA recommends the torque not exceed 111 ft-lb, with a dry lubricant used on the threads. Current ADOT standards call for a torque of 208 ft-lb.

Acceptable vehicular velocity change for both low and high speed impacts occurred in crash tests of ADOT's largest pole, a 13.7-m (45-ft) height steel pole with a 6.1-m (20-ft) luminaire support arm (ADOT standard drawing T.S. 4-9), when the slip-base bolts were torqued to 282 N-m (208 ft-lb). In the low speed test, the pole struck the roof of the vehicle as it fell, causing significant roof deformation. It is not known if a lower bolt torque would have affected pole trajectory in the low speed test. In the opinion of the authors, it would not have made an appreciable difference. Based on previous studies by the authors (9), vehicular velocity change during impact with slip-base supports is not extremely sensitive to the clamping force, at least in the range under consideration. Studies by the authors in the near future, using state-of-the-art finite element vehicular/pole models (7), should provide considerable insight concerning impact performance of light poles as a function of key parameters, including slip-base clamping force and mass distribution.

Until more definitive data become available, and based on results of the crash tests conducted under the present study, changes in the current ADOT bolt torque values do not seem warranted at this time. In general, it is desirable to put the largest torque on the bolts that is permissible without compromising safety or yielding the bolt. The primary reason for this is that sufficient preload or pre-tension in the bolt can reduce or eliminate fatigue concerns.

Pole Installation and Maintenance

Ideally the bolt load would remain equal in each of the three bolts. In reality this is not possible due to variations in the live (wind and ice) and dead (weight of arm and luminaire) loads. To the extent practicable, recommended bolt torques should be applied and verified during installation of the pole. Normally, the foundation base plate is installed and leveled first. Then the pole, with arm and luminaire attached, is erected and the pole base plate is attached to the foundation base plate. Each of the three slip bolts are then torqued to the recommended value while the pole is secured by erection equipment. The final tensile load per bolt will depend on the manner in which the pole is secured during application of bolt torques, and the direction and speed of any wind present during attachment. Actual bolt loads, and the net clamping force, obtained from this method can therefore be expected to vary somewhat from pole to pole.

Evaluation of slip bolt loads through bolt torques, and hence the net clamping force, at some time after installation would be a difficult task. Reasonable and inexpensive procedures by which this could be accomplished are not evident, at least on a large scale. Note that bolt loads immediately after initial pole installation will vary from those obtained during installation. Once the support used during erection and installation is released, the bolt loads will change due to the dead load of the luminaire and its support. Any wind that may be present during inspection will also affect bolt loads. Adjusting bolt torques under these conditions could result in an undesirable net clamping force (either too high or too low), or in one bolt being under-torqued and/or another being over-torqued. These problems could possibly be minimized if the pole could be secured during the inspection in a manner that would tend to neutralize the wind and dead loads. This would require heavy and costly equipment.

TTI researchers have recently begun working on a project in which tightening procedures for large diameter anchor bolts are being investigated (10). As part of this study, the researchers hope to develop a procedure or methodology by which the tension in a bolt can be verified in situ without having to loosen the bolt and retorque it. One proposed method for accomplishing this type of inspection is using ultrasonic transducers. If successful, this technology could be applied to the analogous problem of determining the tension in the slip bolts of a slip-away luminaire support.

At this time, however, no specific post-installation inspection procedure for slip-base bolt torques is offered. However, periodic, visual inspections of slip-base poles should be considered to determine if debris, soil, corrosion, erosion, or other hindrances that could compromise proper actuation of the slip-base are present. This inspection could also identify any obvious problems with slip-base bolts, such as loose or missing bolts/nuts. If loose or missing bolts/nuts are encountered, it is recommended that they be lubricated, replaced, and torqued to the proper value.

Summary

In summary, the following points are offered:

1) Proper performance of slip-base supports depends on the clamping force in the slip-base bolts. However, crash tests and analytical studies indicate performance is not overly sensitive to the clamping force, at least for values used by ADOT.
2) Care should be exercised during pole installation to insure recommended bolt torques are applied uniformly to each of the slip-base bolts, and that the recommended values are not exceeded. Lubricants should be used to minimize friction between the washer and nut, and between the nut and bolt threads.
3) No specific post-installation inspection procedure for slip-base bolt torques is offered. However, periodic, visual inspections of slip-base poles should be considered to determine if debris, soil, corrosion, erosion, or other hindrances that could compromise proper actuation of the slip-base are present. This inspection could also identify any obvious problems with slip-base bolts, such as loose or missing bolts/nuts.

CONCLUSIONS AND RECOMMENDATIONS

A study was undertaken to evaluate the impact performance of ADOT's slip-away bases (ADOT standard drawings T.S. 5-2 and 5-3) for use with ADOT's standard 30-ft, 40-ft, and 45-ft luminaire poles (ADOT standard drawings T.S. 4-4, 4-7, 4-8, and 4-9). Three full-scale crash tests were conducted in accordance with the requirements of *NCHRP Report 350* to accomplish this task. During this test program, ADOT's 13.7-m (45-ft) constant tapered luminaire support was found to exhibit unacceptable impact performance. Although the slip base activated readily and the occupant impact velocity was within recommended limits, a secondary impact of the pole with the roof of the vehicle resulted in substantial deformation of the roof structure. The crush to the roof, which was measured to be 165 mm (6.5 in.), violated the integrity of the occupant compartment and the test was judged to pose a severe hazard to occupants of the vehicle. In addition to the failure of the 13.7-m (45-ft) constant tapered design, it can also be inferred from this testing that ADOT's other 13.7-m (45-ft) pole designs, which weigh more than the constant tapered design, would also exhibit unacceptable behavior.

A similar test of ADOT's standard 12.2-m (40-ft) luminaire system was judged to be marginally acceptable. In this test (test 472360-3) the luminaire support readily yielded to the vehicle and the occupant impact velocities and ridedown accelerations were well within the recommended limits established by *NCHRP Report 350*. Although the test vehicle once again sustained substantial deformation to the roof structure from a secondary impact with the luminaire pole, the magnitude and localized extent of the crush was judged to be within acceptable limits based on results of other approved systems.

Since the current 13.7-m (45-ft) poles were found to be deficient, a significant effort was directed toward identifying approved, crashworthy luminaire systems which provide a mounting height of 13.7 m (45 ft) or greater and could serve as a replacement for the existing design. Several candidate systems were identified which could serve in this capacity, the most promising of which is a steel 4-bolt slip-base design which has a mounting height of 15.8 m (52 ft) and was successfully crash tested. It is also recommended that the current design requirements be carefully reviewed and options for reducing the weight of the existing system be considered. Potential options include using a high-strength steel, reducing the length and weight of the mast

arm, relaxing the static deflection requirements, and lowering the wind load requirements from those resulting from using 25 or 50-year return frequency isotachs, to those resulting from 15-year isotachs.

Maintenance practices related to slip-bolt torque were also reviewed. Although no specific post-installation inspection procedure for slip-base bolt torques is offered at this time, periodic visual inspections of slip-base poles should be considered to determine if debris, soil, corrosion, erosion, or other hindrances that could compromise proper actuation of the slip-base are present. It was also noted that although proper performance of slip-base supports depends on the clamping force in the slip-base bolts, crash tests and analytical studies indicate that the performance is not overly sensitive to the clamping force.

REFERENCES

1. Ross, H. E., Jr. and Sicking, D. L., "Highway Appurtenance Testing, Phase I - Engineering Evaluation of ADOT Highway Safety Features," Final Report on Contract No. 91-0387, November 1991.

2. Abghari, A., Stoughton, R. L., and Dusel, J., "Vehicle Impact Testing of Lightweight Lighting Standards," Report No. 636964, Office of Transportation Laboratory, California Department of Transportation, October 1988.

3. Ross, H. E., Jr., Sicking, D. L., Zimmer, R. A., and Michie, J. A., "Recommended Procedures for the Safety Performance Evaluation of Highway Features," *National Cooperative Highway Research Program Report 350*, Transportation Research Board, National Research Council, Washington, D. C., 1993.

4. FHWA Memorandum from Director of Office of Engineering to Regional Federal Highway Administrators, "Breakaway Sign and Luminaire Supports," Federal Highway Administration, July 6, 1990.

5. *Standards Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals*, American Association of State Highway and Transportation Officials (AASHTO), Washington, D.C., 1990.

6. Pfeifer, B. G., et al., "Full-Scale 1,800-Lb Vehicle Crash Tests on a 4-Bolt Breakaway Slip-Base Design," Research Report TRP-03-25-91, Midwest Roadside Safety Facility, University of Nebraska, Lincoln, Nebraska, August 1991.

7. "Finite Element Models of Roadside Safety Structures," Cooperative Agreement DTFH61-94-X-00035, U.S. Department of Transportation, Federal Highway Administration, scheduled to begin January 1995.

8. *Standards Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals*, American Association of State Highway and Transportation Officials (AASHTO), Interim Specification, Washington, D.C., 1994.

9. Ross, H. E., Jr., Perera, H. S., Sicking, D. L., and Bligh, R. P., "Roadside Safety Design for Small Vehicles," *National Cooperative Highway Research Program Report 318*, Transportation Research Board, National Research Council, Washington, D. C., 1989.

10. "Tightening Procedures for Large Diameter Anchor Bolts," TxDOT Research Study #1472, Texas Department of Transportation, in progress.

APPENDIX A

U.S. Department
of Transportation
**Federal Highway
Administration**

AUG 1 1994

400 Seventh St., S.W.
Washington, D.C. 20590

Refer to: HNG-14

Hayes E. Ross, Jr. P.E.
Professor, Civil Engineering Department
Head, Structural Systems Division, TTI
The Texas A&M University System
College Station, Texas 77843-3135

Dear Mr. Ross:

Thank you for your June 6 letter to Mr. James H. Hatton, Jr. regarding interpretation of the results of your full-scale crash testing of the Arizona three-bolt luminaire slip-base. We have reviewed the video of the testing which accompanied your letter, as well as video footage of other breakaway support tests. Even though Test Number 2 results in acceptable vehicle velocity change and occupant impact speed, we must agree with you that the extensive roof deformation is significant. Therefore, the test results should probably be considered as failing.

Some sign support tests and some luminaire support tests, including your Test Number 3, that we have considered acceptable have resulted in localized roof crush in the 100- to 150-mm range. On the other hand, the magnitude of the roof crush seen in Test Number 2 is so severe all the way from the windshield to the rear window that we consider it unacceptable. In our view, whenever a significant portion of the roof over the seats is deformed more than 125 mm in a crash test, the roof crush should be considered unacceptable. Unfortunately, the Motor Vehicle Safety Standard for vehicle roof strength does not ensure that roof crush will be uniform between vehicle types and models.

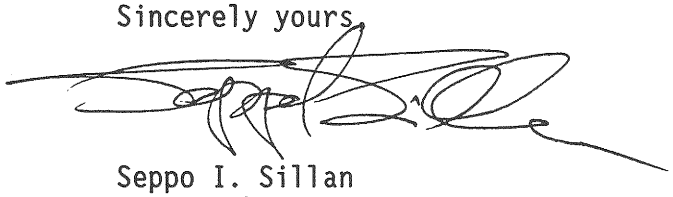
Of course, major contributors to such extensive roof deformation is the mass of the support, a feature under the control of the luminaire support designer. Our current guidance limits the maximum mass of luminaire supports to 453.6 kg, close to the mass of the pole in Test Number 2. In light of the results of Test Number 2 we are re-evaluating guidance, giving thought to placing the acceptable limit for the mass of a support at 375 kg, approximately the mass of the pole used in Test Number 3, which had a maximum roof crush of 120 mm.

You requested guidance from us concerning the maximum torque specified by Arizona for the 31.75-mm diameter clamp bolts in their slip-base luminaire support. The largest bolt diameter addressed under current guidelines is 25.4 mm, with a recommended clamping force per fastener of no more than

AUG 04 1994

16 000 N (3600 pounds), estimated to result from a torque of 84 N·m (62 pound-ft). For the 31.75-mm (1.25-in) bolts used in the Arizona slip-base, a clamping force in the range of 17 800 N (4000 pounds) would be in line with current recommended practice. This equates to approximately 113 N·m (83.3 pound-ft) of torque which is significantly less than the torque specified by Arizona. We believe it would be desirable for Arizona to change its torque requirement to this lower value.

Sincerely yours,



Seppo I. Sillan
Acting Chief, Federal-Aid & Design Division

APPENDIX B

U.S. Department of Transportation
Federal Highway Administration

Memorandum

Subject: ACTION: Breakaway Luminaire Supports (Reply Due: November 1, 1994)

Date: August 19, 1994

From: Acting Chief, Federal-Aid and Design Division

Reply to Attn. of: HNG-14

To: Regional Federal Highway Administrators
Federal Lands Highway Program Administrator

The upper weight limit recognized as acceptable by this office for breakaway luminaire supports has been 1000 pounds (mass of 453.6 kg), including the support, mast arm, and luminaire. This was most recently spelled out in the attachment to our memorandum dated November 12, 1993, "Procedures for Determining Acceptability of Highway Features." Setting an upper limit permits some flexibility in the design of the luminaire support and mast arm without the need for crash testing every combination that results in a different mass or mounting height from that successfully crash tested. The 1000-pound limit was thought to be within the range that would not cause unacceptable damage should the pole fall directly onto the impacting vehicle.

Since most breakaway luminaire support testing has used bogie vehicles or pendulums, there has been very little testing of poles in this mass range using late-model small cars. However, a crash test was conducted by the Texas Transportation Institute (TTI) in March of this year on a 452.2-kg (997-pound) breakaway luminaire support. The test vehicle, a Chevrolet Sprint, experienced an acceptable velocity change, but the falling support caused significant damage to the roof. The roof was crushed from 150 mm to 200 mm along its centerline. We consider this to be unacceptable intrusion into the passenger compartment, as occupants could receive severe injuries from this amount of intrusion.

Some sign support and luminaire support test results that we have considered acceptable have included localized roof crush in the 100- to 150-mm range. However, the magnitude of the roof crush seen in the cited TTI test was severe all the way from the windshield to the rear window. In our view, it would be desirable to limit the acceptable roof crush for that portion of the roof over the seats to no more than about 125 mm in a crash test. Unfortunately, the motor vehicle safety standard for vehicle roof strength does not ensure that roof crush will be uniform between vehicle types or models. In the same test program that produced the unacceptable roof crush, a 386-kg (850-pound) pole falling on a Subaru Justy crushed the vehicle's roof 119 mm (4.7 in). In another test series, a 410-kg (902-pound) pole falling on a Dodge Colt produced an unmeasured but estimated 25- to 40-mm crush of the vehicle's roof.

Based on the crash test evidence, this office is contemplating a change in the upper mass limit we will accept for breakaway luminaire supports. (We anticipate that existing, otherwise acceptable supports that exceed the recommended mass limit would not be subject to replacement.) Before such a change is made we thought it desirable to consult the field offices to determine if problems with massive breakaway luminaire supports have been noted by the States. We also need to know if a significant number of States would have to change their standard luminaire support designs should the mass limit be revised downward. The mass limit being considered is 375 kg.

Your assistance is needed in determining which, if any, States have had a problem with injuries resulting from breakaway luminaire supports crushing vehicles and how extensive the problem may be. Your assistance is also needed in determining which States would be affected by the contemplated 375-kg mass limitation and how extensively they would be affected. We would also like a reading on your's and the States' reactions to lowering the AASHTO's design wind load requirements from those resulting from using 25- or 50-year return frequency isotachs to those resulting from 15-year isotachs to lighten breakaway supports. Reporting your findings to the Office of Engineering, HNG-14, by November 1, 1994, will be very helpful and much appreciated.

Jerry L. Poston

Jerry L. Poston

APPENDIX C

Introduction

Crashworthy luminaire supports are designed to breakaway or yield when struck by a vehicle. Testing parameters and criteria to determine acceptable breakaway performance are found in the AASHTO "Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals."

In 1975 AASHTO issued this combined sign and luminaire support specification and the FHWA adopted the 1975 edition for application on Federal-aid highway projects. During the period from 1976 through 1987 FHWA's Office of Engineering issued numerous letters to luminaire support manufacturers accepting their devices for use on Federal-aid projects. These devices had been tested and produced results which satisfied the criteria in the 1975 edition of the AASHTO specification. The acceptance letters are on file in the Geometric and Roadside Design Branch.

During 1985 AASHTO issued a new edition to the sign and luminaire specification. In 1988 FHWA adopted the 1985 edition of the AASHTO specification for application on Federal-aid projects. Key changes in the 1985 edition involving testing parameters and acceptance criteria for breakaway supports were:

1. The weight of the crash test vehicle was lowered from 2,250 pounds to 1,800 pounds.

2. The criterion for acceptable dynamic performance was changed from a maximum change of momentum of 1,100 pound-seconds for the test vehicle (which implied a change of velocity of 15.7 ft/sec for a 2,250 pound test vehicle) to a maximum change in velocity of 15.0 ft/sec for the new 1,800 pound test vehicle.

3. The establishment of a 4-inch maximum stub height criterion.

Following FHWA adoption of the 1985 edition of the AASHTO specification, the Office of Engineering has been issuing acceptance letters to manufacturers of luminaire support systems which have been tested in accordance with the parameters in the 1985 edition of the AASHTO specification and produced satisfactory performance. A compilation of these acceptance letters is included in this section. Typically, the acceptance letters provide a description along with a drawing of the device tested; test results; and, information on limitations on use of the device, such as the weight of the system tested.

It is noted that breakaway luminaire support systems other than those covered by this compilation could be acceptable for use on Federal-aid highway projects. The FHWA's Office of Engineering has issued these acceptance letters as a service to help promote continuity and uniformity in review. However, it is not a requirement of FHWA that such a letter be issued for each breakaway luminaire support system to be used on a Federal-aid project. If, for a particular luminaire support system, it can be demonstrated to the satisfaction of the highway agency and FHWA's Division Office that a support system has been tested in accordance with recognized procedures and the results are satisfactory, than that support system could be accepted for use on a Federal-aid project by the Division Office.

Luminaire Supports

Listing of FHWA Acceptance Letters

Code	Date	Manufacturer/Supplier	Device
LS-1	6/15/88 11/10/88	Sherman International	Fiberglass Luminaire Support MB 36-D-50-56
LS-2	6/29/88	Akron Foundry	TB Series AL Transformer (TB1-AF 1315-17 and modifications) (See LS-4)
LS-3	6/24/88	Union Metal	Cast Aluminum Base A2940
LS-4	1/12/89	Akron Foundry	Reaffirmation of TB1 bases
LS-5	3/14/89	Hapco Division	Impact Safety Coupling 67238
LS-6	4/4/89 3/5/90	Shakespeare Products	Direct Burial Fiberglass Light Poles Series BH20, BH24, BH30, BH35, BS30, BS35, BX30, BX35, BA41, BA47, BB30, BB35, BB41, BB47, BC30, BC35, BC41, BC47.
LS-7	11/8/89	Shakespeare Products	Fiberglass poles, series AA,AB,AC,AD on Transpo Safety 201 or 301 couplings. Pole heights of 39' to 47'.
LS-8	1/11/90	Transpo Industries	Pole-Safe breakaway couplings for Conventional luminaire supports weighing no more than 900#.
LS-9	1/24/90	Akron Foundry	TB-2 and TB-3 Al Transformer Bases (TB-2 B.C. increased via LS-15)
LS-10	2/26/90	PrecisionForm	PrecisionForm Coupler PFI 200-1 for poles weighing no more than 800#.
LS-11	5/15/90	Union Metal	A2850-C1R10 Al Transformer Base 12.5 inch maximum bolt circle

LS-12	5/14/90	P&K Pole Products	7" & 8" Al shoe bases, 10" slip base
LS-13	5/29/90	P&K Pole Products	10" slipbase
LS-14	5/30/90	Valmont Industries	Cast Al transformer base No. 0283093 15 inch maximum bolt circle
LS-15	5/30/90	Akron Foundry	TB-2 Al Transformer base, 12" B.C. TB-1 Al Transformer base, 950# pole.
LS-16	6/29/90	Valmont Industries	Slip Base specifications
LS-17	8/6/90	Akron Foundry	CS-300 and CS-370 Al Transformer Bases (tests of Feralux bases)
LS-18	8/6/90	Akron Foundry	F-1300 and F-1302 Al Transformer Bases (tests of Pole Lite bases)
LS-19	8/6/90	Akron Foundry	TB-3-17, TB-5-9, TB-6-9 Transformer Bases
LS-20	8/20/90	Union Metal	A2849 Al Transformer Base
LS-21	9/7/90	Shakespeare Products	Fiberglass poles ASW27 thru ASW35 and AHW27 thru AHW35 with Al shoe base
LS-22	9/19/90	Akron Foundry	Chart summarizing approval letters LS-2, LS-4, LS-9, LS-15, LS-19
LS-23	2/7/91 11/20/92	PrecisionForm	Revision to PF200-1 breakaway coupler. Supplement Removes Conditions
LS-24	7/22/91	Akron Foundry	Revisions to TB-1, TB-2, TB-3 Cast aluminum transformer bases
LS-25	10/10/91	Utah DOT	Four-bolt luminaire slip base.
LS-26	6/10/92	Sherman International	Direct Burial Breakaway Fiberglass Luminaire Supports
LS-27	7/20/92 9/1/92	Hapco Division	Breakaway Aluminum Shoe Base
LS-28	7/27/92	Adian Engineering	Adian Breakaway Base for Luminaire Supports Model TB-01
LS-29	4/26/93	Hapco	Extruded Aluminum Bases A73089, A73088
LS-30	1/27/93 (Memo to Regions)	--	FHWA Breakaway Timber Utility Pole (Operational) (Six-bolt slip base)
LS-31	6/17/93	Syro Steel	ADIV Breakaway Timber Utility Pole (Four-bolt slip base)
LS-32	9/3/93	Hapco Division	Cast Aluminum Shoe Bases TP3405 and TP3406
LS-33	10/12/93	Manitoba Safe-T-Base	Cast iron breakaway couplings
LS-34	10/5/93	Millerbernd Manufacturing	Progressive Shear Bases 40C63 and 40C49 on stainless, high carbon, and CORTEN A poles

Revised November 16, 1993
Reprinted May 10, 1994

APPENDIX D

MICHIGAN
DEPARTMENT OF TRANSPORTATION
BUREAU OF HIGHWAYS

SPECIAL PROVISION FOR SIGN SUPPORT AND LIGHT STANDARD ANCHOR BOLTS

D/RDT/skw 1 of 4 11/4/91

Description

Requirements for anchor bolts, nuts, and washers used in sign supports and light standards specified in Subsection 8.07.15 of the 1990 Standard Specifications are modified by the requirements contained herein. This specification also sets forth an installation and tightening procedure for these anchor bolts.

Materials

The material used for anchor bolts shall be medium carbon, hot rolled steel bars meeting the following mechanical requirements:

Yield Strength	50,000 psi
Ultimate Strength	85,000 psi
Elongation (2-inch gage), min	21 percent*
Reduction in Area, min	30 percent**
Longitudinal Charpy V-Notch,min	15 ft-lbs at 40°F

* Elongation (8-inch gage), min 18 percent for bolts tested full section.
**Bolts over 2 to 2 1/2 inch, 22% min; over 2 1/2 to 3 inch 20% min.

Notch toughness tests on specimens shall be performed in accordance with Test Frequency P (Piece Testing) of ASTM A-673 and the notch shall be oriented perpendicular to the longitudinal axis of the anchor bolt. In order to meet the Charpy V-Notch impact requirements, the steel may need to be heat treated.

Anchor bolts, nuts, and washers shall be zinc coated, as indicated on the plans and specifications, in accordance with ASTM A-153. Dimensions of the bolts shall be as shown on the plans.

Threads on the anchor bolts shall be 8UN series as specified in ANSI B1.1 and shall have Class 2A tolerances before coating. After coating the maximum limit of pitch and major diameters may exceed the Class 2A limit by 0.021 inch for bolts 1 inch and smaller, and by 0.031 inch for bolts larger than 1 inch diameter. Anchor bolt threads may be cut or rolled into the round bar stock.

Nuts for anchor bolts shall conform to the requirements of ASTM A563, Grade A, heavy hex. The threads shall be 8UN series as specified in ANSI B1.1 Class 2B tolerances, and tapped oversize after coating by not more than 0.021 inch for nuts 1 inch and smaller, or more than 0.031 inch for nuts larger than 1 inch. The nuts shall be lubricated as specified in Supplementary Requirement S1 of ASTM A563.

Washers shall conform to the requirements of ASTM F436 for circular washers.

All bolts shall be furnished with a Type A certification, including results of yield strength, tensile strength, elongation, reduction of area, and charpy tests, with identification to the heat number of the steel, and to furnace lot number if heat treated. Anchor bolts for cantilever and truss sign supports shall have an identification stamped in the end of the hook to identify them to a specific test report.

In addition to the certification, the Engineer will sample anchor bolts (including nuts and washers) for destructive testing at the following frequency:

Cantilever sign supports - one bolt per cantilever
Truss sign supports - one bolt per truss assembly
Other uses - one bolt per heat per project

Additional bolts shall be ordered to provide for the sampling.

Anchor Bolt Installation

A steel template shall be used to accurately locate and hold the anchor bolts plumb and in proper alignment. This template shall be in place during placement of the concrete base and shall remain in place a minimum of 24 hours after the concrete placement has been completed. The support cage used to position the anchor bolts within the foundation shall remain in the concrete foundation. Out-of-position anchor bolts and anchor bolts greater than 1:20 out-of-plumb are cause for rejection of the base. Bending of the anchor bolts to straighten or move into position, or alternations of the base will not be permitted.

Anchor Bolt Tightening

Anchor bolts shall have their top nuts and leveling (bottom) nuts tightened as follows:

1. All leveling nuts (bottom nuts) shall be brought to full bearing on the bottom of the base plate. The bottom of the leveling nuts must be kept as close to the concrete base as practical, and shall not be more than one inch above the top of the concrete base. Leveling nuts must be threaded onto the anchor bolt to provide at least 1/4-inch projection of the bolt above the top nut (when in its tightened position).

2. Beeswax or equivalent shall be generously added to the top nut bearing face and top nut internal threads prior to placement on the anchor bolt. Tighten all top nuts to a "snug" condition defined as the tightness attained by the full effort of a man using a wrench with a length equal to 14 times the diameter of the anchor bolt, except that the minimum length shall be 18 inches. This snug tightening shall be accomplished in a minimum of two separate passes of tightening. The sequence of tightening in each pass shall be such that the opposite side nut, to the extent possible, shall be subsequently tightened until all the nuts in that pass have been snugged.

3. At this point, the top nut and leveling nut must be in full bearing on the base plate. If any gap exists between either nut and the base plate, a beveled washer shall be added between the nut washer and the base plate to eliminate the gap. The washer shall be stainless steel type 304, shall be the same diameter as the hardened washer, and shall be beveled as required to eliminate the gap between the nut and the base plate. All nuts shall be resnugged in accordance with item 2 above if beveled washers are added.

4. Using a hydraulic wrench (see Note 1), rotate all top nuts an additional 1/3 turn. The additional 1/3 turn of the nuts shall be accomplished by tightening all the nuts in two separate passes of equal incremental turns (i.e., 1/6 turn each pass). The sequence of nut tightening in each pass shall be such that the opposite side nut, to the extent possible, shall be subsequently tightened until all the nuts in that pass have been turned. There shall be no rotation of the leveling nut during top nut tightening.(See Note 1)

5. Tightness of the nuts shall be checked in the presence of Department personnel a minimum of 48 hours after the nuts have been rotated the additional 1/3 turn. Tightness of the top nuts shall be checked by applying a torque to the nut in accordance with the following values:

Bolt diameter (inches)	Torque (foot-pounds)
1	300
1 1/4	630
1 1/2	1120
1 3/4	1820
2	2770
2 1/4	4010
2 1/2	5550

Bottom leveling nuts shall be in contact with the base prior to applying the torque. Any nuts found loose shall be retightened in accordance with the above procedure. (See Note 1)

After the anchor bolt nuts have been checked for tightness, the bolts will be ultrasonically tested by the Department before final acceptance (Project Engineer will contact Steve Cook at 517-322-5709 of Materials & Technology Division to arrange for testing). Ultrasonic testing and calibration procedures that will be used by the department for final acceptance testing are available to the contractor upon request. This final testing is to assure that no flaws in the bolts have been introduced during the construction process. The contractor must test to verify the absence of flaws prior to the erection stage. Reflectors found with an indication rating less than 15 decibels will be cause for rejection of the entire base installation. Replacement of the base installation shall be done at the contractor's expense.

Measurement and Payment

The completed work and materials as described above (including furnishing anchor bolts for destructive testing) will not be paid for separately; payment for this work will be considered as having been included in the contract unit prices bid for the foundations or other pay items in the contract.

Note 1: Hydraulic wrenches capable of accomplishing this tightening and applying the specified torque for tightness checking are available for rent or purchase from the following companies.

American Bolt Tightening
Kevin Kaska
37742 Northland
Livonia, MI 48152
313-591-2055

Hytorc Great Lakes
Troy Corp.
423 Harpers Way
Lansing, MI 48917
517-321-7187

This information is provided soley for the contractor's convenience.

MICHIGAN
DEPARTMENT OF TRANSPORTATION
BUREAU OF HIGHWAYS

SPECIAL PROVISION FOR CANTILEVER SIGN SUPPORT ERECTION

D/RDT/skw 1 of 2 12/1/90

Description

This specification sets forth the erection procedure for cantilever sign supports, which is in addition to the procedure cited in Subsection 6.26 of the Standard Specifications. Cantilever sign support erection shall be done as specified herein and other special provisions.

Erection Procedure

Erection of the cantilever sign supports shall be done in accordance with the sequence indicated below. Traffic shall be maintained during erection in accordance with other special provisions.

1. Bottom leveling nuts and washers shall be placed on all the anchor bolts. These nuts shall initially be placed 1/4-inch above the concrete foundation. The nuts shall then be brought into level with the highest nut above the foundation. Clearance between the concrete foundation and the bottom leveling nuts shall not exceed 1-inch maximum.

2. The column only, without the arm brackets attached, shall be placed on the leveled bottom nuts and washers.

3. The two top nuts perpendicular and the two top nuts parallel to the sign face (in its final position) shall be placed on the anchor bolts, along with their corresponding washers, and loosely snug tightened.

4. The column base plate shall be leveled by adjusting only the nuts perpendicular and parallel to the sign face (in its final position).

5. Remaining top nuts and washers shall be placed on the anchor bolts and loosely snug tightened.

6. All bottom nuts and top nuts shall now be tightened in accordance with the Special Provision for Sign Support and Light Standard Anchor Bolts.

7. Place the assembled arm bracket, without the sign, on the erected column. All bolts shall be tightened in accordance with the turn-of-the-nut method specified in Subsection 5.04.35 of the Standard Specifications. Any nuts and bolts loosened or removed after being fully tightened shall not be reused. Retightening previously tightened bolts that have been loosened by the tightening of adjacent bolts will not be considered as reused.

8. Place the sign panel on the erected arm bracket. The holes in the aluminum mounting supports, which receive the sign panel mounting U-bolts, shall be field drilled in locations such that the sign panel is horizontal in its final position.

9. The anchor bolt nuts connecting the column base to the concrete foundation shall now be checked for tightness in accordance with the Special Provision for Sign Support and Light Standard Anchor Bolts. If any washers or nuts are found loose, the nuts shall be retightened in accordance with the Special Provision for Sign Support and Light Standard Anchor Bolts.

10. The anchor bolt nuts shall be rechecked for tightness a minimum of 48 hours after the nuts have been rotated the additional 1/3 turn, as specified in the Special Provision for Sign Support and Light Standard Anchor Bolts.

11. Final evaluation of the support installation by ultrasonic inspection must be done by the department prior to acceptance. This evaluation will be done in accordance with the Special Provision for Sign Support and Light Standard Anchor Bolts.

Measurement and Payment

The completed work as described above will not be paid for separately; payment for this work will be considered as having been included in the contract unit prices bid for other pay items in the contract.