Technical Report Documentation Page

1. REPORT No.
FHWA/CA/TL-88/07

2. GOVERNMENT ACCESSION No.

3. RECIPIENT'S CATALOG No.

4. TITLE AND SUBTITLE
Vehicle Impact Testing of Lightweight Lighting Standards

5. REPORT DATE
October 1988

6. PERFORMING ORGANIZATION

7. AUTHOR(S)
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8. PERFORMING ORGANIZATION REPORT No.
636964

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Office of Transportation Laboratory
California Department of Transportation
Sacramento, California 95819

10. WORK UNIT No.

11. CONTRACT OR GRANT No.
F82TL17

12. SPONSORING AGENCY NAME AND ADDRESS
California Department of Transportation
Sacramento, California 95807

13. TYPE OF REPORT & PERIOD COVERED
Final

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES
This project was performed in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. ABSTRACT
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All the lighting standards tested met the requirements of NCHRP Report 230 with minor exceptions. The 1985 AASHTO Standard Specifications for breakaway bases, however, were met in all seven crash tests. Although the die-cast aluminum coupling proved to be an effective breakaway device when impacted by 1800-lb cars, excessive porosity and lack of compliance with Caltrans specifications preclude the use of these couplings as a standard Caltrans breakaway device. The Caltrans triangular steel slip base proved to be an effective breakaway device when impacted by 1800-lb cars.

17. KEYWORDS
Lighting standards, lightweight steel, aluminum, luminaire breakaway devices, aluminum couplings, crash tests, vehicle

18. No. OF PAGES:
315

19. DRI WEBSITE LINK
http://www.dot.ca.gov/hq/research/researchreports/1981-1988/88-07.pdf

20. FILE NAME
88-07.pdf

STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF NEW TECHNOLOGY AND RESEARCH
OFFICE OF TRANSPORTATION LABORATORY

VEHICLE IMPACT TESTING OF LIGHTWEIGHT LIGHTING STANDARDS

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88-07

70-88

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO. FHWA/CA/TL-88/07	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
4. TITLE AND SUBTITLE VEHICLE IMPACT TESTING OF LIGHTWEIGHT LIGHTING STANDARDS		5. REPORT DATE Oct. 1988
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) A. Abghari, R. L. Stoughton, and J. Dusel		8. PERFORMING ORGANIZATION REPORT NO. 636964
9. PERFORMING ORGANIZATION NAME AND ADDRESS Office of Transportation Laboratory, California Department of Transportation, Sacramento, California 95819		10. WORK UNIT NO.
		11. CONTRACT OR GRANT NO. F82TL17
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17. KEY WORDS Lighting standards, lightweight steel, aluminum, luminaire breakaway devices, aluminum couplings, crash tests, vehicle.	18. DISTRIBUTION STATEMENT No Restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161

19. SECURITY CLASSIF. (OF THIS REPORT) Unclassified	20. SECURITY CLASSIF. (OF THIS PAGE) Unclassified	21. NO. OF PAGES 238	22. PRICE

DS-TL-1242 (Rev.6/76)

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CONVERSION FACTORS

English to Metric System (SI) of Measurement

Quality	English unit	Multiply by	To get metric equivalent
Length	inches (in)or(")	25.40 .02540	millimetres (mm) metres (m)
	feet (ft)or(')	.3048	metres (m)
	miles (mi)	1.609	kilometres (km)
Area	square inches (in^2) square feet (ft^2) acres	6.432×10^{-4} .09290 .4047	square metres (m^2) square metres (m^2) hectares (ha)
Volume	gallons (gal) cubic feet (ft^3) cubic yards (yd^3)	3.785 .02832 .7646	litre (l) cubic metres (m^3) cubic metres (m^3)
Volume/Time (Flow)	cubic feet per second (ft^3/s	28.317	litres per second l/s)
	gallons per minute (gal/min)	.06309	litres per second (l/s)
Mass	pounds (lb)	.4536	kilograms (kg)
Velocity	miles per hour (mph) feet per second (fps)	.4470 .3048	metres per second (m/s) metres per second (m/s)
Acceleration	feet per second squared (ft/s^2)	.3048	metres per second squared (m/s^2)
	acceleration due to force of gravity (G) (ft/s^2)	9.807	metres per second squared (m/s^2)
Density	(lb/ft^3)	16.02	kilograms per cubic metre (kg/m^3)
Force	pounds (lbs) (1000 lbs) kips	4.448 4448	newtons (N) newtons (N)
Thermal Energy	British termal unit (BTU)	1055	joules (J)
Mechanical Energy	foot-pounds (ft-lb) foot-kips (ft-k)	1.356 1356	joules (J) joules (J)
Bending Moment or Torque	inch-pounds (in-lbs) foot-pounds (ft-lbs)	.1130 1.356	newton-metres (Nm) newton-metres (Nm)
Pressure	pounds per square inch (psi) pounds per square foot (psf)	6895 47.88	pascals (Pa) pascals (Pa)
Stress Intensity	kips per square inch square root inch ($ksi\sqrt{in}$)	1.0988	mega pascals$\sqrt{metre}$ ($MPa\sqrt{m}$)
	pounds per square inch square root inch ($psi\sqrt{in}$)	1.0988	kilo pascals$\sqrt{metre}$ ($KPa\sqrt{m}$)
Plane Angle	degrees (°)	0.0175	radians (rad)
Temperature	degrees fahrenheit (F)	$\frac{°F - 32}{1.8} = °C$	degrees celsius (°C)

Acknowledgements

This research was sponsored by the United States Department of Transportation, Federal Highway Administration.

Special appreciation is due to the following staff members of the Transportation Laboratory for their enthusiastic and competent help on this project:

Crash crew - Test preparation and execution, data gathering, processing and analysis; Doran Glauz, Jim Keesling, Lee Wilson, Roy Steiner, Duane Anderson, Bob Ratcliff, Sue Hawatky, C. J. Bennett, John Bitterman, and Chuck McGinn. Temporary employees who assisted; Mike Scarbrough, Paul Goryl, Nela Pana, and John Dautel.

Electrical Instrumentation - Test preparation and execution, data processing; Richard Johnson, supervisor; Bill Ng, Del Gans, and Pablo Gonzalez.

Project secretarial work; Jane Hallstrom.

Machine Shop - Ed Girdler, supervisor; Roy Steiner, Gene Weyel, and Jesse Perez.

Welding and Metallurgy - Bill Crozier, supervisor; Paul Hartbower.

Drafting Unit - Eddie Fong, supervisor; Irma Gamarra-Remmen.

The following persons outside the Transportation Laboratory also made valuable contributions, and their assistance is appreciated:

Headquarter photo section - High speed cameras and still photography; Pete Asano, Supervisor; Ed Anderson, Don Tateishi, Lynn Harrison, Fran Johnston, and Jamie Cameron.

Headquarter graphic services section - Documentary movies and film report; Larry Moore and Gary Pund.

The authors also gratefully acknowledge the valuable technical consultation provided by Ed Tye, Caltrans Division of Traffic Engineering, and Earl Riker, Caltrans Division of Structures.

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APPENDIX B: Photo-Instrumentation

Several high-speed movie cameras were used to record the impact during crash tests. The types of cameras used and their locations are shown in Figures B1 through B5. The cameras were electrically activated from a central control console located adjacent to the impact area except for three which had their own battery power and were turned on by three separate operators.

All high-speed cameras were equipped with timing light generators which exposed reddish timing pips on the film at a rate of 1,000 per second. The pips were used to determine camera frame rates and to establish time/sequence relationships. Data from the high speed movies were reduced on a Vanguard Motion Analyzer. Some procedures used to facilitate data reduction for the test are listed as follows:

1- Butterfly targets were attached to the top and sides of the test vehicle. Figure A1 (Appendix A) shows the target locations. The targets established scale factors and horizontal and vertical alignment. The area of impact on the lighting standard was outlined using contrasting colors of tape, Figure B6.

2- Flashbulbs, mounted on the test vehicle, were electronically triggered to establish (a) initial vehicle/lighting standard contact (b) application of the vehicle brakes and (c) beginning and ending of sliding weight travel. The impact flashbulbs had a delay of several milliseconds before lighting up.

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1. Introduction

1.1 Problem

Lightweight passenger cars are becoming an increasingly significant portion of the national fleet. In 1982 the National Highway Traffic Safety Administration (NHTSA) estimated that the ratio of small cars (compact and smaller) to large cars (midsize and larger) in operation in the United States would be equal by 1986 with the smaller cars dominating thereafter. Because of this, the criteria for crash tests have changed over the years to correspond to the car population.

The steel breakaway lighting standards used along California highways were qualified in 1975 and before with crash tests using 2250 and 4500-lb passenger vehicles (14,15). Due to the aforementioned rapid increase in the number of smaller passenger vehicles, recommended crash test procedures published in 1981 by the National Cooperative Highway Research Program (NCHRP), Report 230 (19), calls for crash tests with 1800-lb cars. The current steel lighting standard designs may be too massive to comply fully with the new crash test criteria. Also, there is concern that the current triangular slip base breakaway energy can increase with time due to the weathering effects (dirt and corrosion) and the tendency of the zinc layers to pressure weld with a high clamping force. A lighter weight lighting standard requiring less breakaway energy could possibly reduce injuries to occupants of small cars and needs to be evaluated. Also it would be desirable to find a simpler breakaway mechanism which requires less energy to initiate slip or fracture, in which the breakaway energy or slip characteristics would not change with time, which is easier to install or replace and which is less prone to error by installers.

1.2 Objectives - Scope

The primary objective of this research project was to determine, through full-scale crash tests, if a suitable lightweight lighting standard with a breakaway base could satisfy the new crash test criteria recommended in NCHRP Report 230 for 1800-lb cars (19). The aim was to find a lighter weight lighting standard than type 31 steel lighting standards widely used by the California Department of Transportation (Caltrans). Also an attempt was made toward finding a simpler breakaway mechanism at the base of the poles which would require less energy to break away than the typical triangular slip base.

In the original proposal, full-scale tests with aluminum and fiberglass lighting standards equipped with aluminum breakaway couplings were scheduled. Also, two tests were planned using the Caltrans type 31 steel lighting standard with the standard triangular slip base. These would serve as control tests. Test results from aluminum and fiberglass lighting standards would then be compared with those obtained for the current Caltrans type 31 steel design. It was hoped that an aluminum or fiberglass lighting standard would be qualified as a replacement.

Fiberglass lighting standards obviously have some advantages over the metal poles such as light weight, appearance, and lack of corrosion. The most obvious problem; however, is the large deflection of poles with long (20 ft) mast arms under the design loads. Other factors such as the need to use truss-type aluminum mast arms for lengths greater than 8 to 10 ft, maintenance costs, short fatigue life of pole to mast arm connections, lack of interchangeability with the existing lighting standards in case of knockdowns, and lack of comprehensive product specifications ruled out further consideration and testing of the fiberglass lighting standards. Thus, it was decided to examine aluminum lighting standards, a modified type 31 lighting standard made from a thinner gage steel, and the standard Caltrans type 31 steel design. Aluminum breakaway couplings were used with the two aluminum and one of the modified type 31 lighting standards as a possible replacement for the standard triangular slip base.

A total of seven full-scale vehicular crash tests (401 to 407) were conducted. 1979 Honda Civics weighing 1800 lb were used as the crash vehicles. All tests were carried out according to the recommended procedures in NCHRP Report 230 (19), as follows:

Tests 401 and 402 were conducted using a lightweight type 31 lighting standard made from aluminum (35 ft high pole shaft with 20 ft mast arm and total weight of 394 lb) and equipped with aluminum breakaway couplings. These two tests were carried out according to the crash test conditions for test designations 62 and 63 of NCHRP Report 230 (19), head-on at the center point of the bumper at 20 mph and head-on at the quarter point of the bumper at 60 mph, respectively.

In Test 403 a modified type 31 lighting standard made from a thinner gage steel (35 ft high pole shaft with 20 ft mast arm and total weight of 651 lb) and equipped with die-cast aluminum couplings were used. This test was conducted according to the test designation 63 of NCHRP Report 230.

Although results of Tests 401, 402, and 403 met the evaluation criteria of test designations 62 and 63 of NCHRP Report 230, an excessive amount of porosity was observed in the fractured die-cast aluminum couplings after impact. Because of this, a considerable amount of testing was done on both the die-cast aluminum couplings manufactured by Transpo Industries, Inc. and the extruded aluminum couplings manufactured by Aluminum Company of America (ALCOA). As a result of these laboratory tests and x rays, a comprehensive specification controlling aluminum couplings was written (Appendix E). Since neither the die-cast nor the extruded aluminum couplings complied with the newly formulated specifications for aluminum couplings, the use of aluminum couplings was discontinued and it was decided to use the standard Caltrans type 31 triangular slip base for the rest of the project.

Tests 404 and 405 were conducted according to test conditions 62 and 63 of NCHRP Report 230, head-on at the quarter point of the bumper at 60 mph and head-on at the center point of the bumper at 20 mph respectively. In these two tests the typical type 31 lighting standard (35 ft high pole shaft with 20 ft mast arm and weight of 883 lb) with typical triangular slip bases were used.

In Tests 406 and 407 a modified type 31 lighting standard made from a thinner gage steel (35 ft pole with 20 ft mast arm and weight of 630 lb) with triangular slip base were used. These two tests were also carried out and evaluated according to test criteria 62 and 63 of NCHRP Report 230 respectively.

Test data were recorded by both electronic instrumentation and high speed motion picture photography, and the results were compared with those recommended by NCHRP Report 230 (19). The results were also compared with the newly proposed 1985 AASHTO Specifications.

A set of specification compliance tests (x rays, and static tests including tensile, restrained shear, fatigue, and corrosion tests) were developed and tests were conducted on both the Transpo die-cast aluminum couplings, and the ALCOA extruded aluminum couplings.

1.3 Literature Search - Background

The concept of a breakaway mechanism was initiated by the Road Research Laboratory of the Ministry of Transport in England in the late 1950's (5). The preliminary research indicated that, in order to minimize the occupant injury and the damage to a vehicle colliding with a highway appurtenance, a breakaway device, i.e; a mechanism which yields when struck by a vehicle, but strong enough to withstand the static and the wind loads, should be incorporated at the base of the appurtenance. Since then, much research effort has been directed toward developing new breakaway systems.

According to a survey by the Texas Transportation Institute (TTI), until late 1966 most states did not use breakaway devices for their highway appurtenances (7). On August 1, 1966, the Federal Highway Administration (FHWA) issued an Instructional Memorandum which stated that breakaway or yielding supports should be used for the sign supports and lighting standards adjacent to the shoulders of federally funded highways (7).

By 1967, TTI had conducted a state of the art study to determine the impact characteristics of various support and base mounting designs in use at that time. In addition, they developed a slip base with multidirectional breakaway characteristics for their luminaire supports. This study consisted of full-scale crash tests of various support designs which were the first tests of this type conducted in the United States (22).

The TTI slip base consisted of two identical plates which have slots at the apexes of an equilateral triangle (Figure 1). The bottom plate was rigidly attached to the foundation (Figure 1-b), and the top plate was welded to the luminaire support shaft (Figure 1-c). The two plates were clamped together with bolts through the slots (Figure 1-a). The clamping force had to be large enough to prevent slip base separation when the lighting standard is

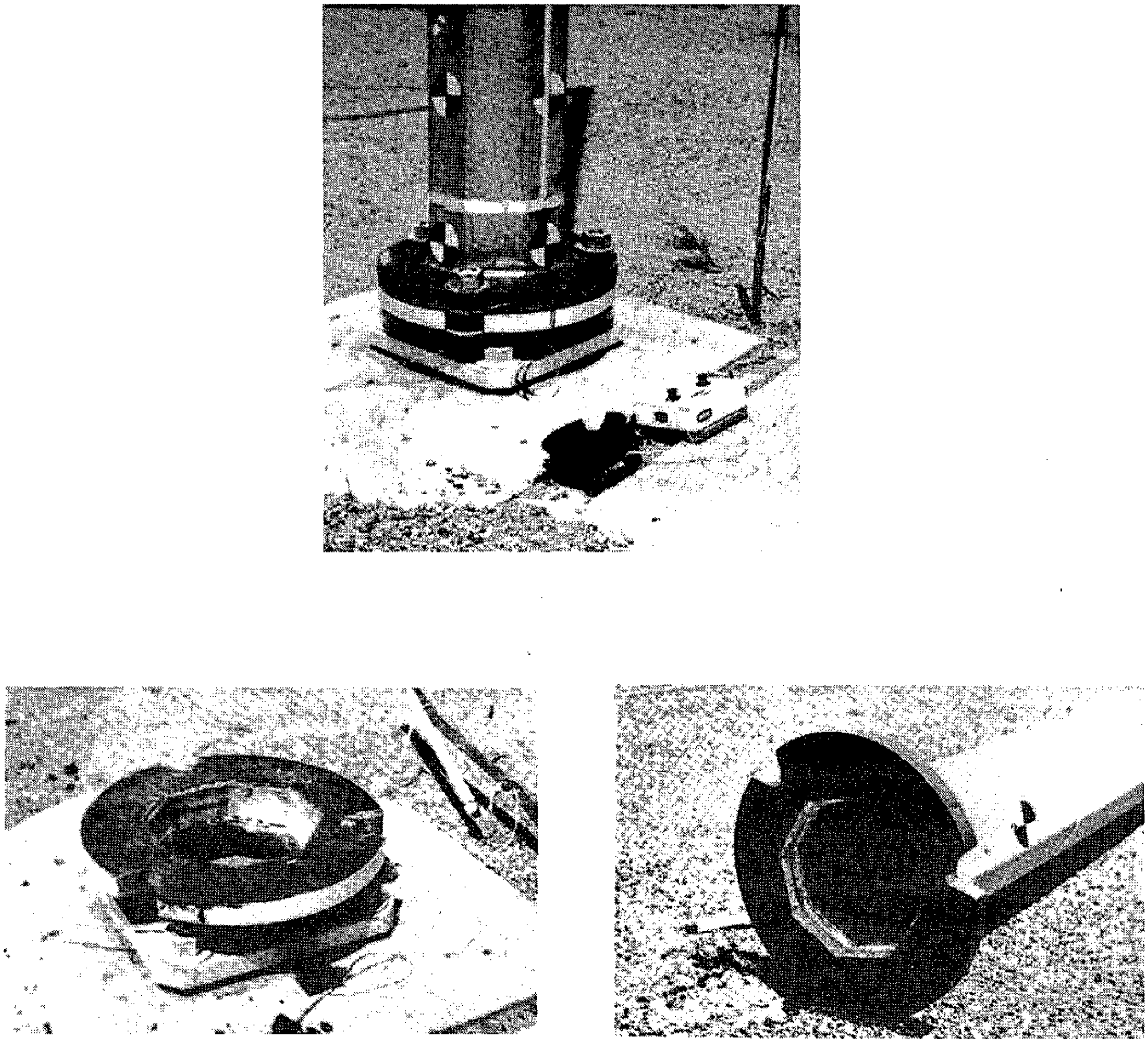


Figure 1. Details of the TTI Slip Base

subjected to live loads, yet small enough to insure low energy slippage when the standard is impacted.

Two full-scale crash tests (Tests S2 and S3) were conducted by TTI in 1968 to verify the effectiveness of the TTI slip base design used with a 40 ft luminaire shaft. The vehicle used for Test S2 weighed 3400 lb, and the one used for Test S3 weighed 3500 lb. The relative severity of impact was measured by comparing vehicle momentum before and after the collision, as this represented the impulse force delivered to the vehicle by the support. Table D1 (Appendix D) shows the summary of the tests results. Results for other types of supports are given in the 1968 Highway Research Record No. 222 (22). The results from full-scale crash tests showed that the breakaway mechanism greatly reduced the severity of the vehicle impact.

During 1968-69 TTI conducted a NCHRP project to study and evaluate different breakaway base concepts. The study was directed toward evaluation of breakaway base concepts and development of design recommendations which could be applied to minimize the safety hazards associated with luminaire support collisions. NCHRP Report 77, "Development of Design Criteria for Safer Luminaire Supports", (5) contains the results of this study. The results regarding slip base supports are given in Table D1 (Appendix D).

In 1968 the California Department of Transportation (Caltrans) conducted a series of full-scale vehicular crash tests on lighting standards with various types of breakaway devices (15). The objective of the study was to determine the effectiveness of five different breakaway lighting standard base designs in reducing the severity of vehicular impact. Ten head-on tests were conducted using identical 1966 sedans weighing 4540 lb and nominal impact speeds of 15 or 40 mph, with the planned point of impact near the midpoint of the bumper. The California type XV steel lighting standards (28'-6" high with 12-ft mast arm and 30 ft luminaire mounting height) were used in all tests with the exception of one tapered aluminum design. Two of these tests were carried out using a multidirectional slip base very similar to the one developed by TTI, but modified to accommodate the California type XV steel pole base configuration.

All breakaway designs tested showed a significant reduction in impact resistance at 40 mph when compared to conventional rigid base design; however, some offered very little reduction in impact resistance when impacted at 15 mph. The TTI multidirectional slip base's overall breakaway performance was superior to all other designs and was considered to be one of the most effective devices for the reduction in severity of vehicle impacts into lighting standards at all speeds and angles. Test results showed that the impact resistance of the slip base was relatively independent of the impact velocity. Table D1 (Appendix D) shows the summary of test results for slip base design. Results of other types of breakaway devices can be found in reference (15).

In California, the first slip base design used by Caltrans appeared in the July 1969 standard plans. With a few modifications, it has been the standard ever since. In the late 1960's and early 1970's Caltrans replaced over 30,000 fixed base lighting standards with slip base standards.

The acceptance criteria for breakaway luminaire supports set by FHWA in June 1968 (9) specified a limit on change in vehicle momentum of 1100 lb-sec (4890 N-sec). This was based on the data then available. The vehicle weight and impacting speed were not specified. A second set of criteria issued by FHWA in November of 1970 (8) called for 400 lb-sec (1780 N-sec) momentum change for pendulum tests, which were popular because of the low cost compared to full-scale crash tests .

The design of lighting standards used along California highways has changed over the years. Larger lighting standards with longer mast arms (up to 30 ft) became popular as designers were trying to provide more clear space between the edge of the roadway and fixed objects. The slip base was also modified to fit the larger diameter, thicker walled poles with longer mast arms. Some other minor modifications were also made. Because the increased mast arm length caused a significant increase in the wind-induced loads, it was necessary to increase the torque in each of the three slip base clamping bolts. This resulted in a total clamping force considerably above that used in 1968 tests. By 1975 the number of small compact passenger cars on highways had also increased significantly. With the increase in the size of lighting standard and mast arm, and the decrease in automobile size, the effectiveness of the slip base was in question.

The first comprehensive set of crash test guidelines was published in NCHRP Report 153 (21), "Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances", in 1974. The three appraisal factors were (a) structural adequacy, (b) impact severity, and (c) vehicle trajectory hazard. Two tests were suggested for breakaway or yielding supports. A 4500-lb (Test 1) and a 2250-lb (Test 2) vehicle impacting the test article at the center of the bumper at 40 and 20 mph respectively. A maximum momentum change of 1100 lb-sec was recommended for the impact severity criterion (for Test 1 only). A lower limit of 750 lb-sec was preferred and was stated as a desirable goal for new devices.

In 1975, the AASHTO specifications (26) set the same criteria of 1100 lb-sec (4890 N-sec) change in momentum as the FHWA criteria; however, the AASHTO specified a 2250-lb (1820 kg) test vehicle and required satisfactory performance over a speed range of 20 mph (32.2 km/h) to 60 mph (96.6 km/h). The specification also called for a maximum desirable momentum change of 750 lb-sec (3340 N-sec) to minimize accident severity.

In the spring of 1975, Caltrans conducted a research project titled, "Dynamic Tests of Breakaway Lighting Standards Using Small Automobiles" (14). The objective of the study was to determine the effectiveness of the modified slip base used with type 31 lighting standards when struck by small cars. Two full-scale crash tests were conducted using 1971 Ford Pintos weighing 2265 lb. The California type 31 steel lighting standards (35 ft high with 30 ft long mast arm) were used and the impact velocities were 17.5 mph and 34.5 mph respectively. The changes of vehicle momentum measured in both cases were 689 and 746 lb-sec which were well below the maximum of 1100 lb-sec (4892 N-sec) and close to the desirable maximum of 750 lb-sec (3335 N-sec) specified in NCHRP Report 153 (21) and AASHTO Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals (26). It was concluded that the relatively high slip base bolt torque did not seriously affect the slip characteristics of the device and that the type 31 slip base was an effective breakaway device when impacted by small cars. With minor modifications, the slip base design continued to be the standard breakaway device for use with the type 30 and 31 lighting standards.

After 1975, ENSCO Inc. conducted a study for FHWA which involved analysis, computer simulation, and laboratory and full-scale tests to develop practical laboratory acceptance test criteria for breakaway supports (16, 17). Good agreement between the predicted vehicle momentum change and those of the full-scale tests confirmed the validity of their mathematical models (16). It was shown that at low impact speed, the vehicle crush characteristics and base fracture energy (BFE) are the dominant factors, while at high impact speed, the inertia of the pole is the dominant term in the vehicle momentum change. The change in vehicle velocity, dv, is the critical parameter affecting occupant safety because immediately after impact, the velocity of an unrestrained occupant relative to the vehicle interior is about the same as the dv of the vehicle. It has been shown that the upper limit of velocity change for head and chest injuries is 11 mph (18). For a specified limit of dMv (momentum change), the lightest vehicle experiences the highest dv. Also for the same breakaway support and speed of impact, the lighter vehicle experiences a large dMv.

In February, 1978, an updated version of NCHRP Report 153 was published as Transportation Research Circular (TRC) 191, "Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances" (20). The circular eliminated Test 1 (4500-lb car at 40 mph) and replaced it with a test using 2250-lb car at 60 mph. The momentum change requirements were also changed to meet the 1975 AASHTO specifications.

In March, 1981, revised crash test procedures were published in NCHRP Report 230 (19), "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances", to correspond to the continuous increase in the lightweight car population. These procedures recommended two crash tests on breakaway or yielding supports using 1800-lb cars, Test 62, head-on at the center point of bumper at 20 mph, and Test 63, head-on at the quarter point of bumper at 60 mph.

It was thought that 1800-lb cars might have difficulty in meeting the new crash tests guidelines when impacting the heavy steel type 31 lighting standard. Also, as mentioned before, the breakaway characteristics of the slip base are a function of the clamping force and friction between the two plates, which can change with time due to weathering. Thus, there was a concern that even if the type 31 triangular slip base met the criteria at the time of installation, it might fail at some time after the installation. So, the aim of this research project was to find a lighting standard that weighs less than the type 31, and a simpler breakaway base which requires less energy to initiate slip or fracture and in which the breakaway energy or slip characteristics would not change with time .

During 1981-1982, ENSCO conducted a similar study for FHWA -Laboratory Procedures to Determine the Breakaway Behavior of Luminaire Supports in Mini-Sized Vehicle Collisions, (12) on a 1003 lb surrogate lighting standard with a triangular slip base similar to the one used by Caltrans. The summary of test results are given in Table D1 (Appendix D). The study was continued in 1984-1985 using the Federal Outdoor Impact Laboratory (FOIL) reusable bogie vehicle (11). The bogie simulated a 1979 VW Rabbit's off-center crush properties, weight (1800 lb), center of gravity location, and moments of inertia. Tests were performed on two types of poles with Caltrans type 31 slip bases, a steel pole on a transformer base and an aluminum pole on ALCOA type 100 couplings. The results regarding slip base and aluminum couplings are given in Table D1.

A series of tests were recently performed at the FOIL to evaluate the currently accepted breakaway devices according to the 1985 AASHTO breakaway criteria. The results regarding slip bases and couplings are given in Table D1, (Appendix D). Discussion of the test results is given in section 5.3.6.

2. Conclusions

The following conclusions can be drawn from the seven full scale crash tests conducted in this research project.

1- All the lighting standards tested met the requirements of NCHRP Report 230, except that the structural adequacy criteria were not fully satisfied because of small intrusions of the poles into the passenger compartment of the car or adjacent traffic lanes. All lighting standards tested, however, met the 1985 AASHTO Standard Specifications for breakaway bases.

2- The die-cast aluminum couplings manufactured by Transpo Industries proved to be an effective breakaway device when impacted by 1800-lb cars. The results showed a maximum change in velocity of 12.4 fps. However, use of aluminum couplings in general is not recommended as a standard Caltrans breakaway device at this time because of the following conditions:

A- Excessive porosity was observed on the fractured surfaces of the couplings and subsequent x rays proved that the couplings were not acceptable based on Caltrans specifications and limits in ASTM E505 reference radiographs.

B- The two downstream anchor bolts bent upon impact. This may cause excessive cost of repairing or replacing the damaged anchor bolts. This problem, however, has apparently been solved in some of the new couplings by the use of a flush mounted female anchor system.

C- The results of tension and shear tests of aluminum couplings showed that neither the die-cast nor the extruded aluminum couplings available at the time tests were conducted complied with the Caltrans aluminum coupling specifications (Appendix E).

3- The 35-ft-high lightweight aluminum lighting standard with 20-ft-long truss type mast arm proved to be effective and reusable after it was impacted at 20 mph, but was damaged at 60 mph. The large deflection due to wind load and the higher cost, however, are the main disadvantage over steel poles.

4- The 35-ft-high lightweight steel lighting standard with 20-ft-long mast arm sustained serious damage after it was impacted at 60 mph.

5- The triangular steel slip base proved to be an effective breakaway device when impacted by 1800-lb cars. The relatively high slip base bolt tension did not appear to affect the slip base performance.

6- Neither the trajectory and final position (after impact) of any of the lighting standards tested nor luminaire debris would create serious hazard or likelihood of injuries to either occupants of the impacted vehicle or to passengers of vehicles in the outside traffic lane.

7- In most slow speed crashes, the pole base is likely to fall on the cars roof.

8- Based on the results from all seven crash tests conducted, injuries to occupant of the impacting vehicle would be expected to be relatively minor provided that the impacting vehicle has a roof.

9- Damage to the crash vehicles in all seven tests was repairable.

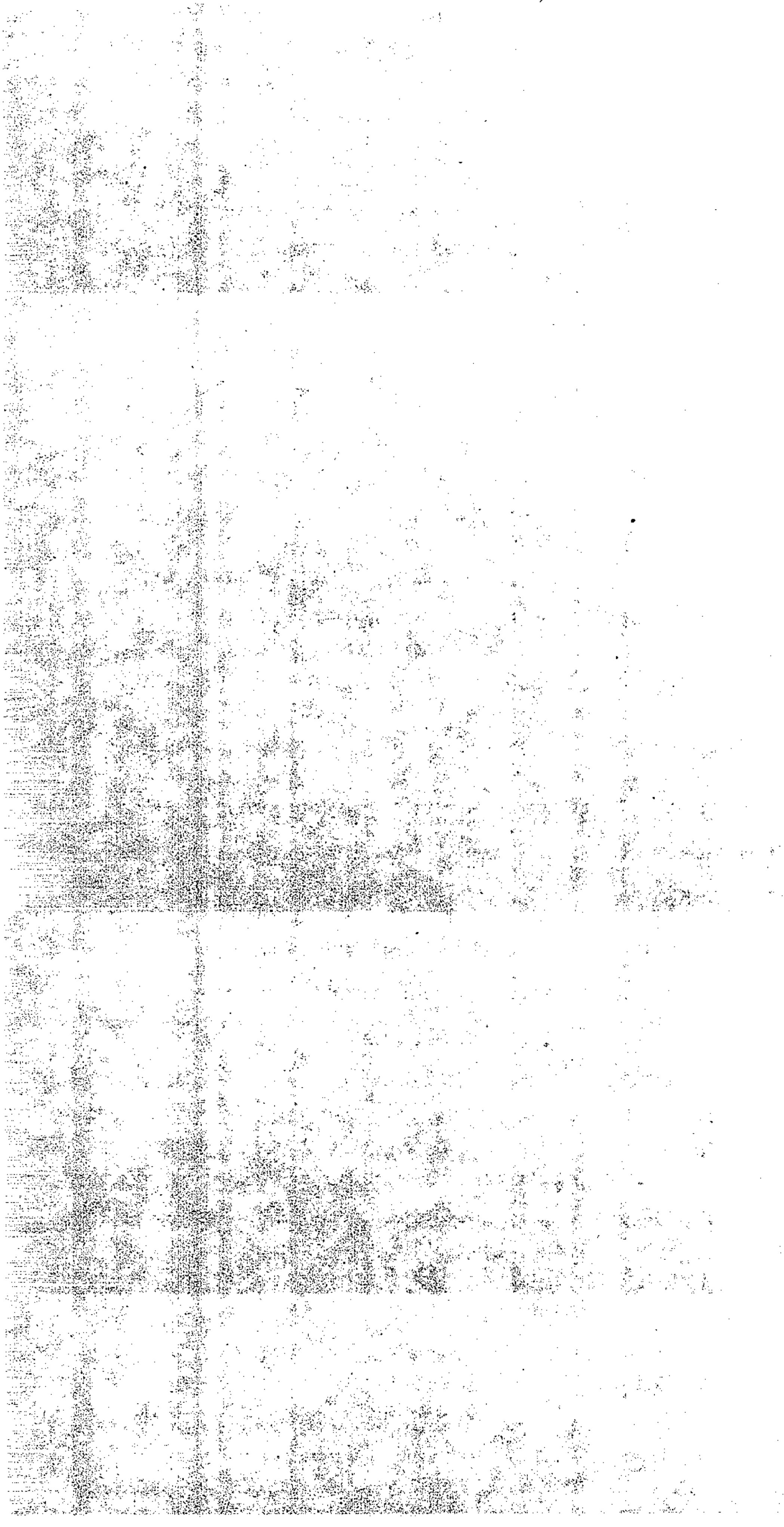
3. Recommendations

Since the current Caltrans type 31 lighting standard with the triangular slip base, as shown on drawings ES-6E and ES-6D (Figures 5, and 6) of the Caltrans Standard Plans of January 1988, met the requirements of NCHRP Report 230 and 1985 AASHTO, it can continue to be used as a breakaway lighting standard along highways.

Die-cast aluminum couplings might be used as effective breakaway devices, provided that the manufacturers upgrade their quality control program so that couplings comply with the Caltrans specifications. Extruded aluminum couplings, as currently manufactured, are too strong and cause excessive damage to anchor bolts.

Since, in five of seven crash tests, debris from broken luminaires fell into the outer traffic lane (even a relatively small piece of luminaire debris could cause some hazard to the following car), it is recommended that lighting standard manufacturers attach luminaire components more securely to the luminaire housing, and make housing and connection to mast arm stronger.

The lightweight steel lighting standard should be considered for use; some changes, however, in the design are necessary if it is desired that the pole be reuseable after impact.



4. Implementation

Design and use lightweight steel poles with triangular slip bases. They would be easier to install and would cost less than the current Caltrans type 31.

Structures Design should draw plans for new lightweight lighting standards, whose outside dimensions would make parts interchangeable with the current type 31 lighting standards.

5. Technical Discussion

5.1 Test Conditions

5.1.1 Test Facilities

All seven full-scale vehicular crash tests (Tests 401-407) were conducted at the Caltrans Dynamic Test Facility in West Sacramento, California. The tests took place on a flat paved asphalt concrete surface.

The die-cast aluminum couplings manufactured by Transpo Industries, and the extruded aluminum couplings manufactured by Aluminum Company of America (ALCOA) were tested at the Translab in Sacramento, California, to determine if they complied with the Caltrans specifications (Appendix E). Dimensional checks, direct tension (short term loading), restrained shear loading (pairs of couplings), fatigue tests (cyclic loading), and corrosion tests were performed.

To evaluate the porosity defects of the aluminum couplers, x rays and radiographic evaluation (per reference radiographs ASTM E505) were performed by Industrial Testing International, Inc. in Sacramento, California, and verified by expert technicians at the Translab.

Concrete foundations (unreinforced, class B), 2.5-ft-diameter and 5-ft-deep were constructed and anchor bolts were installed according to the breakaway base configuration. Lighting standards in Tests 401, 402, and 403 were equipped with breakaway aluminum couplings. The Caltrans triangular slip base typically used on type 31 lighting standards was used as a breakaway device in Tests 404, 405, 406, and 407. Lighting standards were assembled and erected by a District 3 maintenance crew.

5.1.2 Materials - Lighting Standards and Breakaway Bases

5.1.2.1 Lighting Standards

In an attempt to find a lightweight lighting standard which would satisfy the new recommended crash test criteria of NCHRP Report 230 for 1800-lb cars, both aluminum and fiberglass lighting standards were considered. As mentioned earlier, the use of fiberglass lighting standards was ruled out because of the large deflection of poles with long mast arms, fatigue characteristics, and maintenance cost. Thus, crash tests were conducted using aluminum lighting standards and a modified Caltrans type 31 steel lighting standard made from a thinner gage steel. Also, control crash tests were conducted using the regular Caltrans type 31 steel lighting standard.

1 - Aluminum Lighting Standards

Since it was thought that an 1800-lb Honda Civic impacting a Caltrans type 31 steel lighting standard would probably sustain serious damage and could not be reused, it was decided to use aluminum lighting standards in the first two crash Tests, 401 and

402.

The aluminum lighting standard (with truss type aluminum mast arm) used in Tests 401 and 402 is shown in Figure 2. It was manufactured by Hapco of Abingdon, Virginia. The pole height installed was 35 ft. The shaft tapered from 10 in. (base OD) to 8 in. (top OD) and the wall thickness was 0.188 in. The pole base was reinforced with a 2-ft-long aluminum cylindrical sleeve section, 0.257-in.-thick, inserted and welded inside the pole to insure that the shaft had sufficient strength to resist crushing or denting in the vehicle contact area. This also insure a quick transfer of impacting force to the breakaway support causing optimal performance of the breakaway base.

The hand hole used in the current Caltrans type 31 lighting standard which is required to provide working space for wiring the luminaire was eliminated from the aluminum poles with aluminum couplings. By using aluminum couplings, there would be enough space around the couplings for wiring. Elimination of the hand hole would provide more strength at the bottom of the pole, and would reduce manufacturing costs.

A 4-bolt base flange was used to correspond to the aluminum couplings which were used as the breakaway device for Tests 401 and 402. To minimize weight and excessive luminaire deflection, the 20-ft-long mast arm was built as a truss. The mast arm had a 30 in. rise. A GE 400 watt high pressure sodium luminaire weighing 48 lb was installed at the end of the mast arm. To simulate the actual

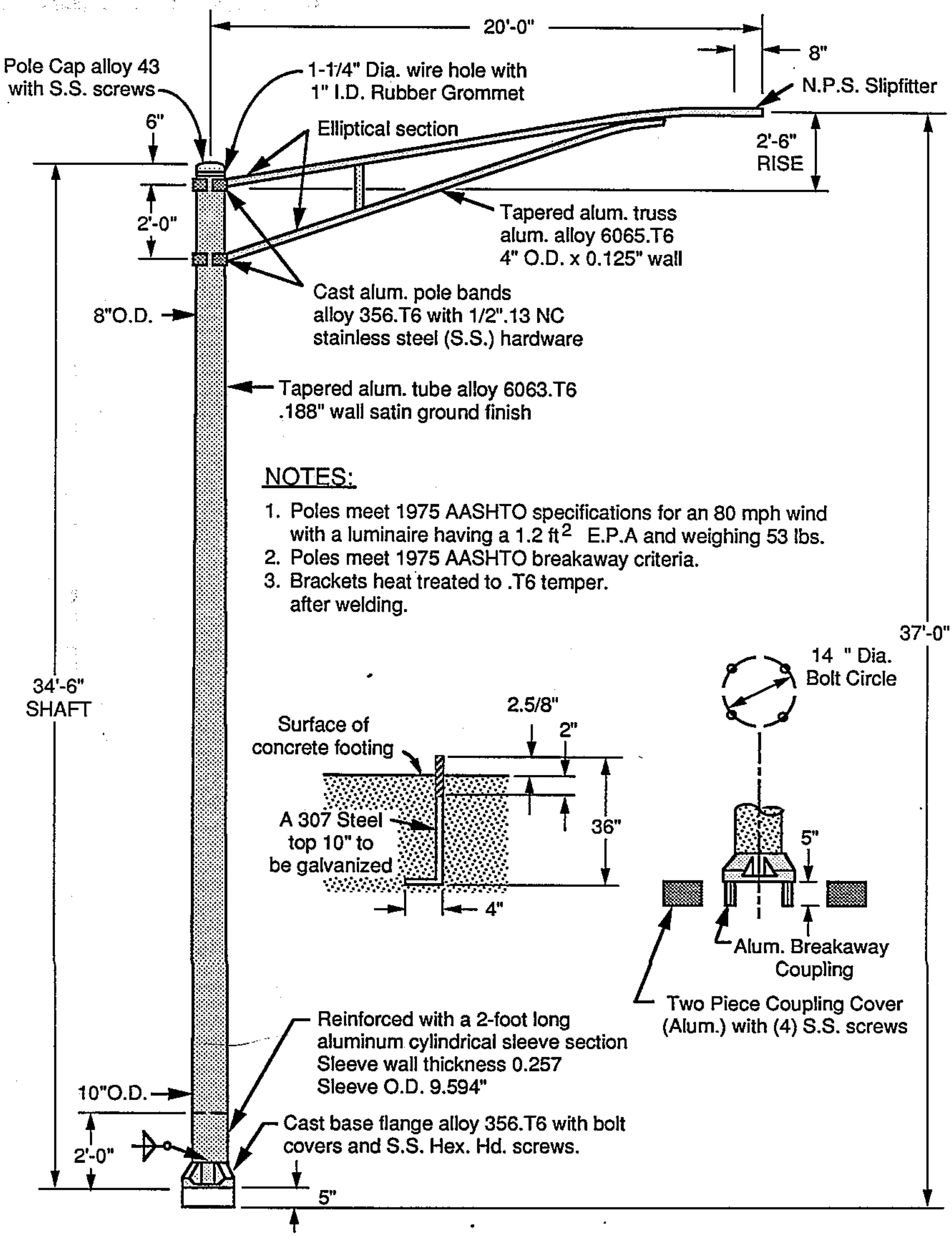


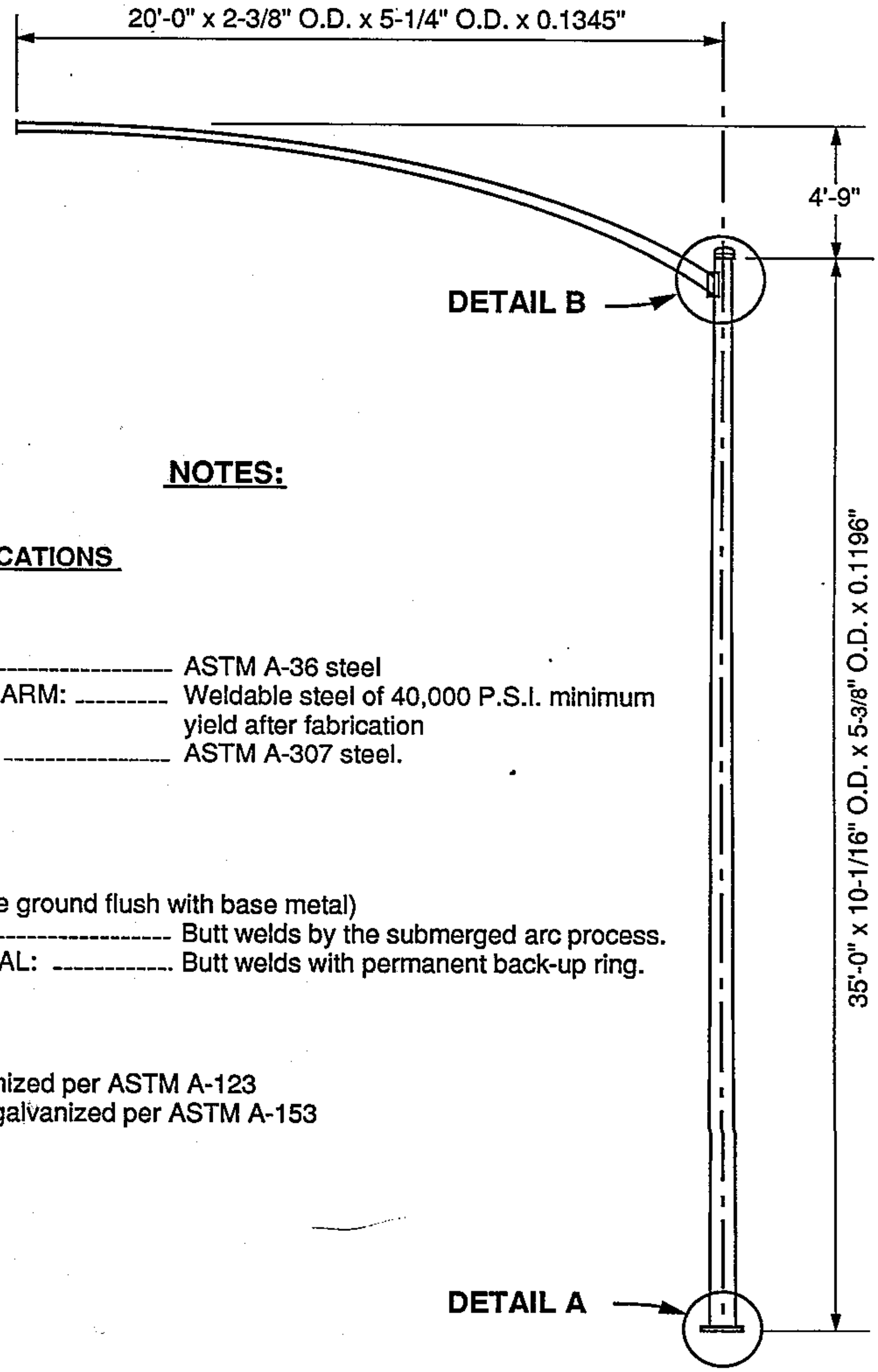
Figure 2. Aluminum Lighting Standard Used in Tests 401 and 402

field conditions and full breakaway resistance, the luminaire was wired with two No. 14 THW wires. The wires ran from the 40 watt GE luminaire at the end of the mast arm, down inside the mast arm and shaft and through a conduit loop cast into the foundation. A fuse connector was crimped onto the bottom end of each wire. The total weight of the lighting standard including the luminaire was 394 lb.

2- Modified Caltrans type 31 Steel Lighting Standard

A modified Caltrans type 31 lighting standard made from a thin gage steel (11 gage, 0.1196-in.-thick) was used in Test 403. The outside dimensions of this lightweight steel lighting standard were the same as the current Caltrans type 31 lighting standard. Similar lighting standards (with the exception of the shaft base diameter and thickness, and shaft manufacturer) were used in Tests 406 and 407.

The lighting standard used for Test 403 was manufactured by Ameron Pole Products, Division of Oakland, California (Figure 3). The tapered shaft (35'-0" X 10-1/16" OD X 5-3/8" OD) weighed 461 lb. The shaft was reinforced at the bottom with a 2-ft-long x 10 gage (0.1345-in.-thick) steel cylindrical sleeve section, inserted inside the shaft and welded to the base plate. A 4-bolt base plate was used to correspond to the aluminum couplings which were used as the breakaway device for Test 403. The 20-ft-long mast arm (20'-0" X 5-1/4" OD, X 2-3/8 " OD) was manufactured from 10 gage (0.1345-in.-thick) steel and weighed 132 lb. The luminaire used was an ITT 400 watt fixture with a high pressure sodium lamp weighing 48 lb. To simulate the real condition, the luminaire was wired



NOTES:

POLE SPECIFICATIONS

MATERIAL:

ALL PLATES: ---------------------- ASTM A-36 steel
POLE AND MAST ARM: --------- Weldable steel of 40,000 P.S.I. minimum yield after fabrication
ANCHOR BOLTS: ---------------- ASTM A-307 steel.

WELDS:

(All butt welds to be ground flush with base metal)
LONGITUDINAL: ----------------- Butt welds by the submerged arc process.
CIRCUMFERENTIAL: ----------- Butt welds with permanent back-up ring.

FINISH:

Pole hot-dip galvanized per ASTM A-123
Hardware hot-dip galvanized per ASTM A-153

Figure 3. Modified Caltrans Type 31 Steel Lighting Standard Used in Test 403

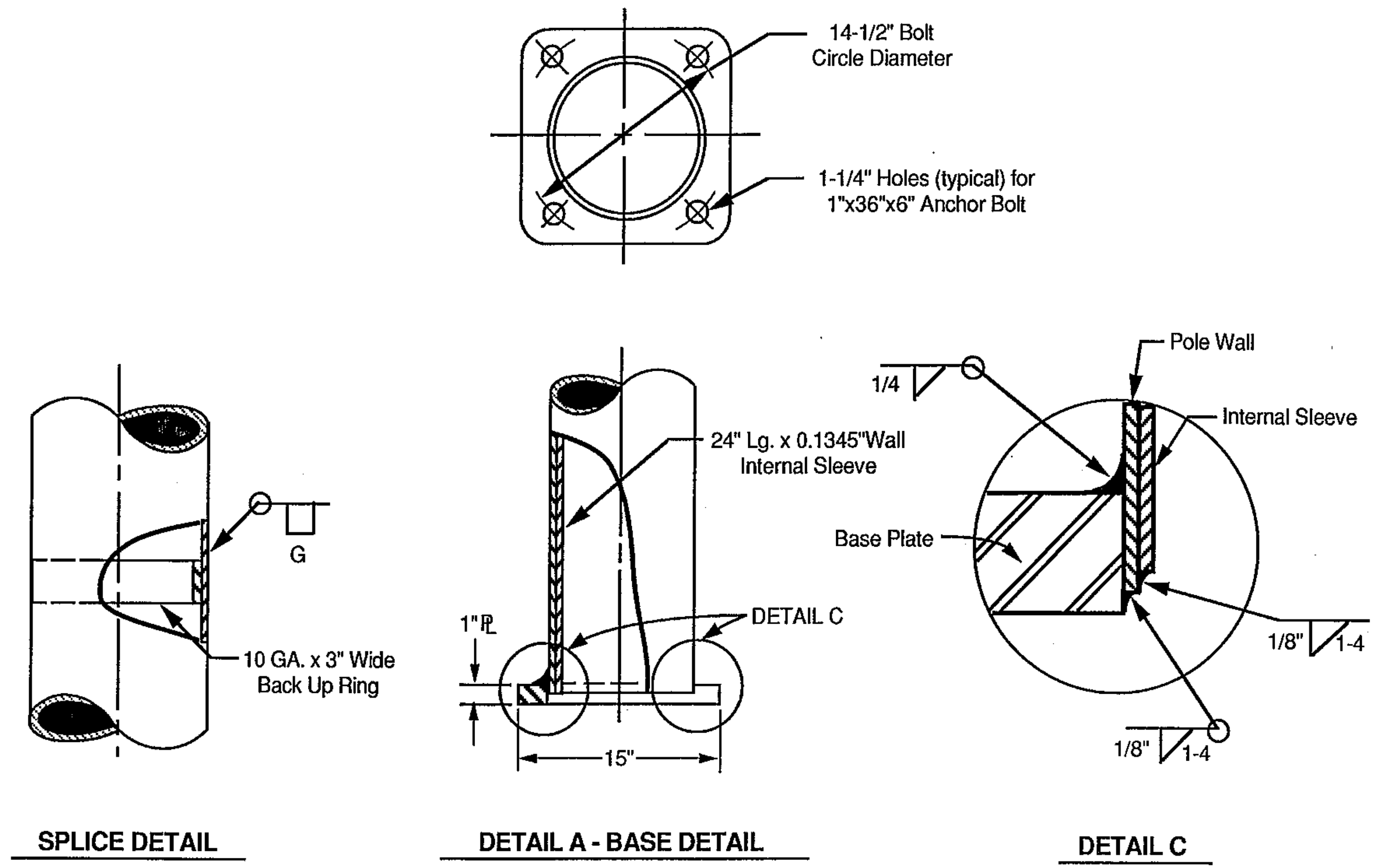
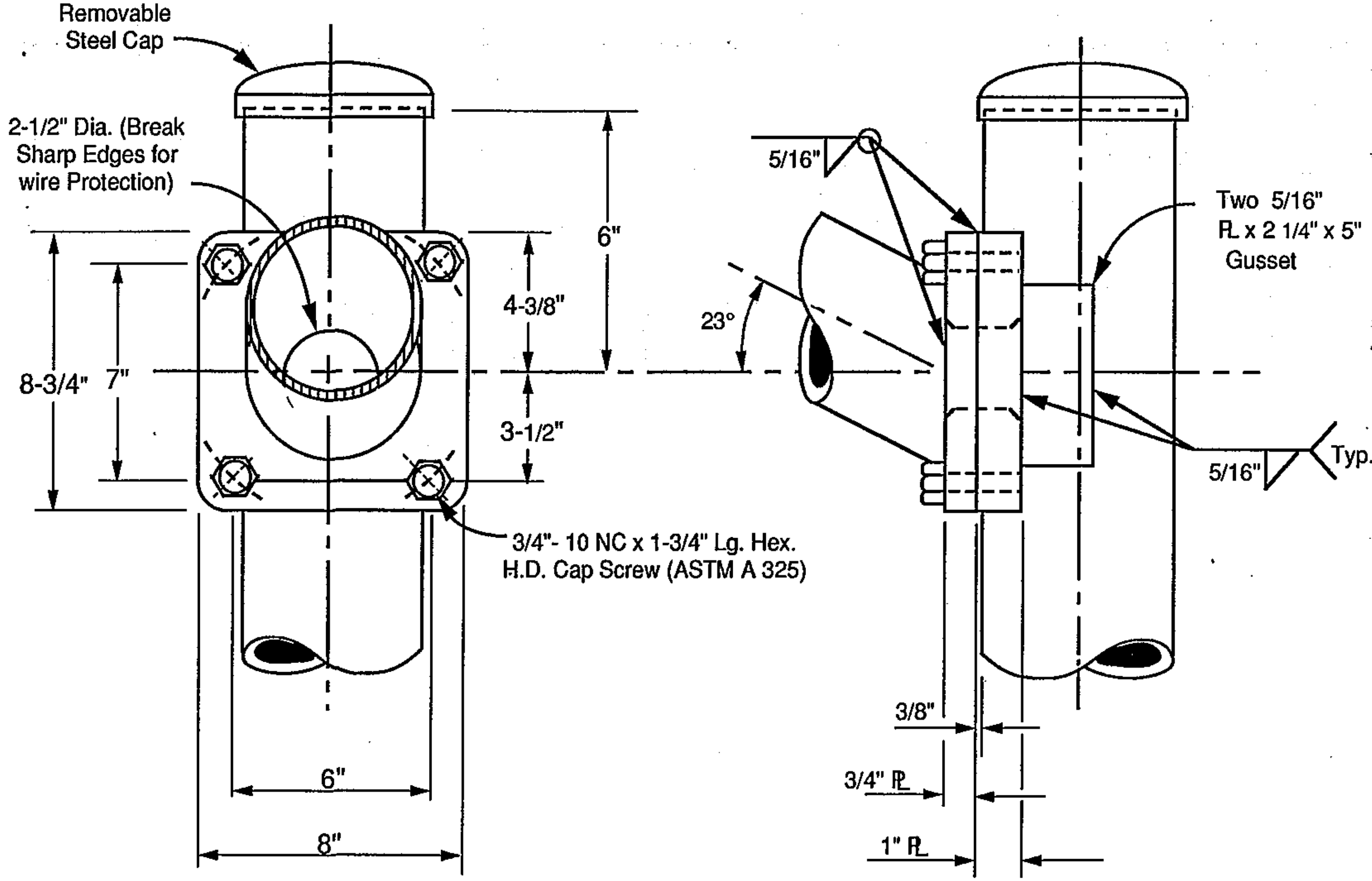


Figure 3 (Cont.). Base Plate Details



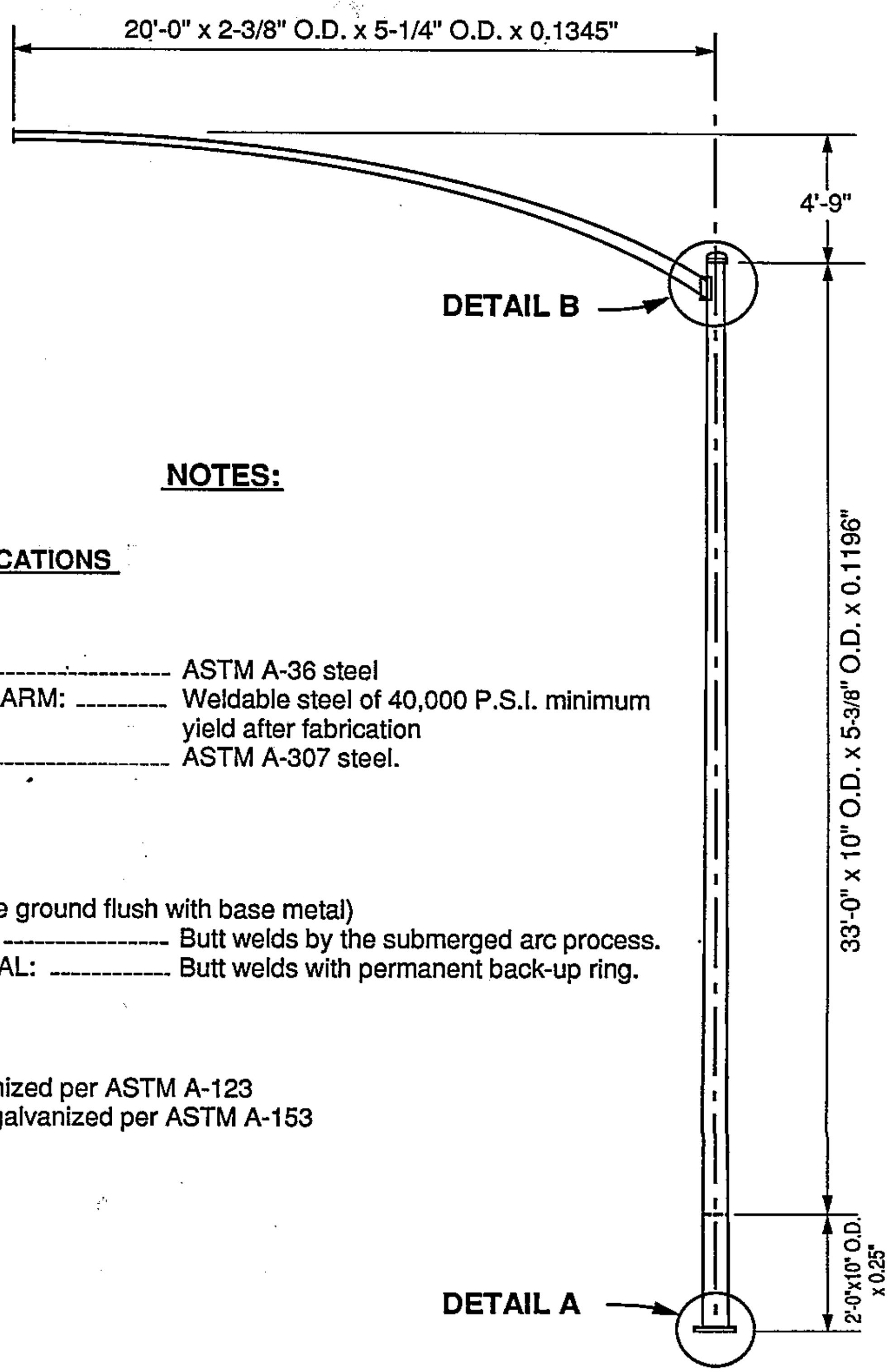
DETAIL B

Figure 3 (Cont.). Luminaire Arm Connection using two No. 14 THW wires which ran from the luminaire at the end of the mast arm, down inside the mast arm and the shaft and through a conduit loop cast into the foundation. A fuse connector was crimped onto the bottom end of each wire. The weight of the other miscellaneous parts including the end cap and 4 couplings studs with washer and nuts was 9.2 lb. The total weight of the system was 651 lb, approximately 240 lb less than a Caltrans standard type 31 lighting standard.

The shafts of the lighting standards used in Tests 406 and 407 were manufactured by Valmont industries of Nebraska (Figure 4). The shaft consisted of a 2-ft-long steel pipe (10-in.-diameter, and 1/4-in.-thick) at the bottom to insure a quick transfer of the impact shear to the breakaway base without damage to the pole, welded to an upper tapered section (33'-0" X 10-0" OD X 5-3/8" OD) made of 11 gage (0.1196 in.) steel. The mast arm previously used in Test 403 was undamaged and was reused for Tests 406 and 407. The luminaires used in Tests 406 and 407 were 310 watt. The total weight of the lighting standard assemblies without the breakaway base parts which would remain behind when impact occurred, were 627.4 and 639.4 lb for Tests 406 and 407, respectively.

3- Caltrans Type 31 Steel Lighting Standards

In Tests 404 and 405 (control tests), a Caltrans type 31 steel lighting standard manufactured by Valmont Industries of Nebraska was used. The standard tested consisted of a galvanized steel pole 35-ft-high and a mast arm 20-ft-long as detailed in the 1984 edition of the California Standard Plans ES-6D AND ES-6E shown in



NOTES:

POLE SPECIFICATIONS

MATERIAL:

ALL PLATES: ---------------------- ASTM A-36 steel
POLE AND MAST ARM: ---------- Weldable steel of 40,000 P.S.I. minimum yield after fabrication
ANCHOR BOLTS:------------------ ASTM A-307 steel.

WELDS:

(All butt welds to be ground flush with base metal)
LONGITUDINAL: ------------------ Butt welds by the submerged arc process.
CIRCUMFERENTIAL: ------------- Butt welds with permanent back-up ring.

FINISH:

Pole hot-dip galvanized per ASTM A-123
Hardware hot-dip galvanized per ASTM A-153

Figure 4. Modified Caltrans Type 31 Steel Lighting Standard Used in Tests 406 And 407

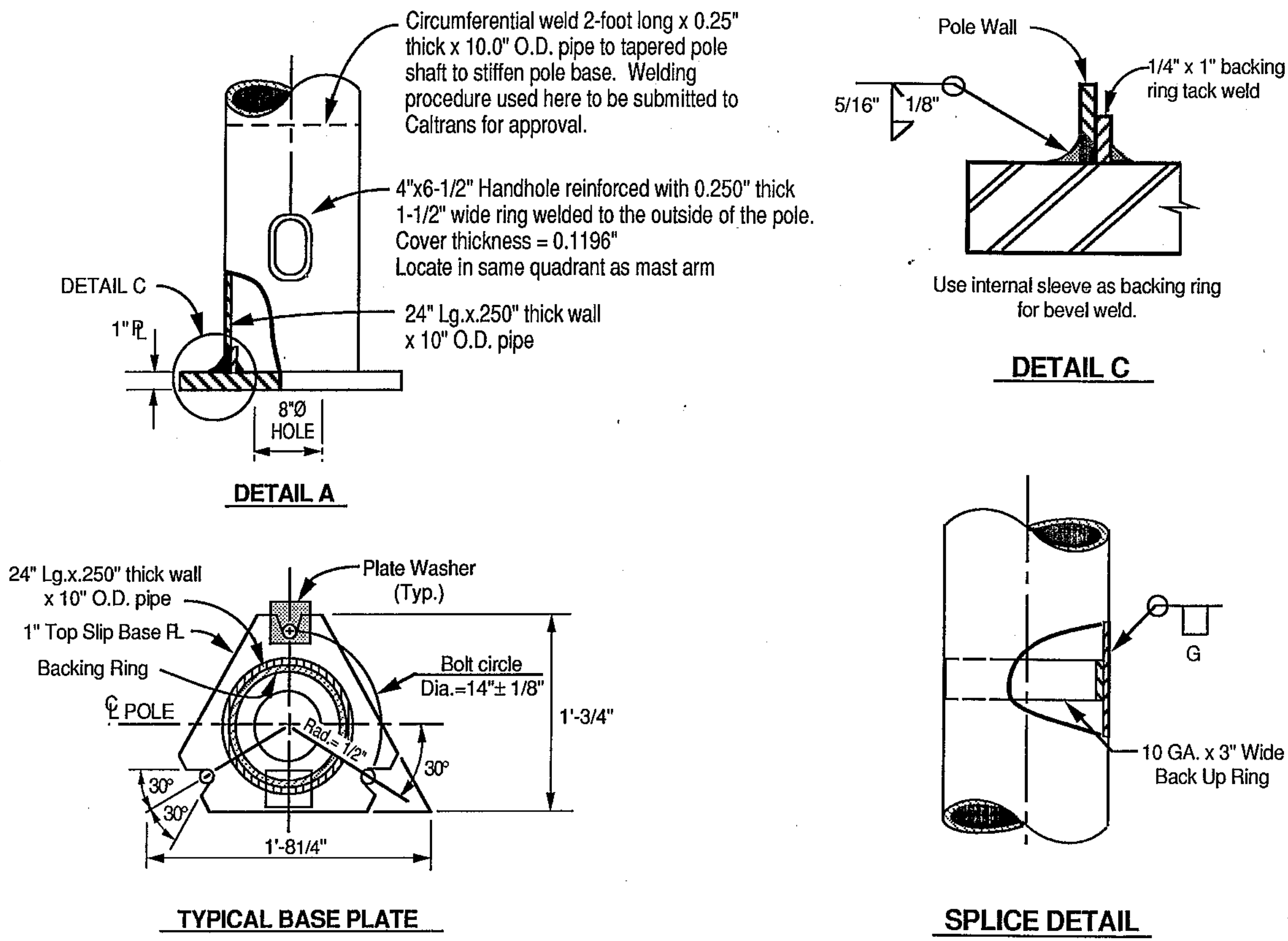
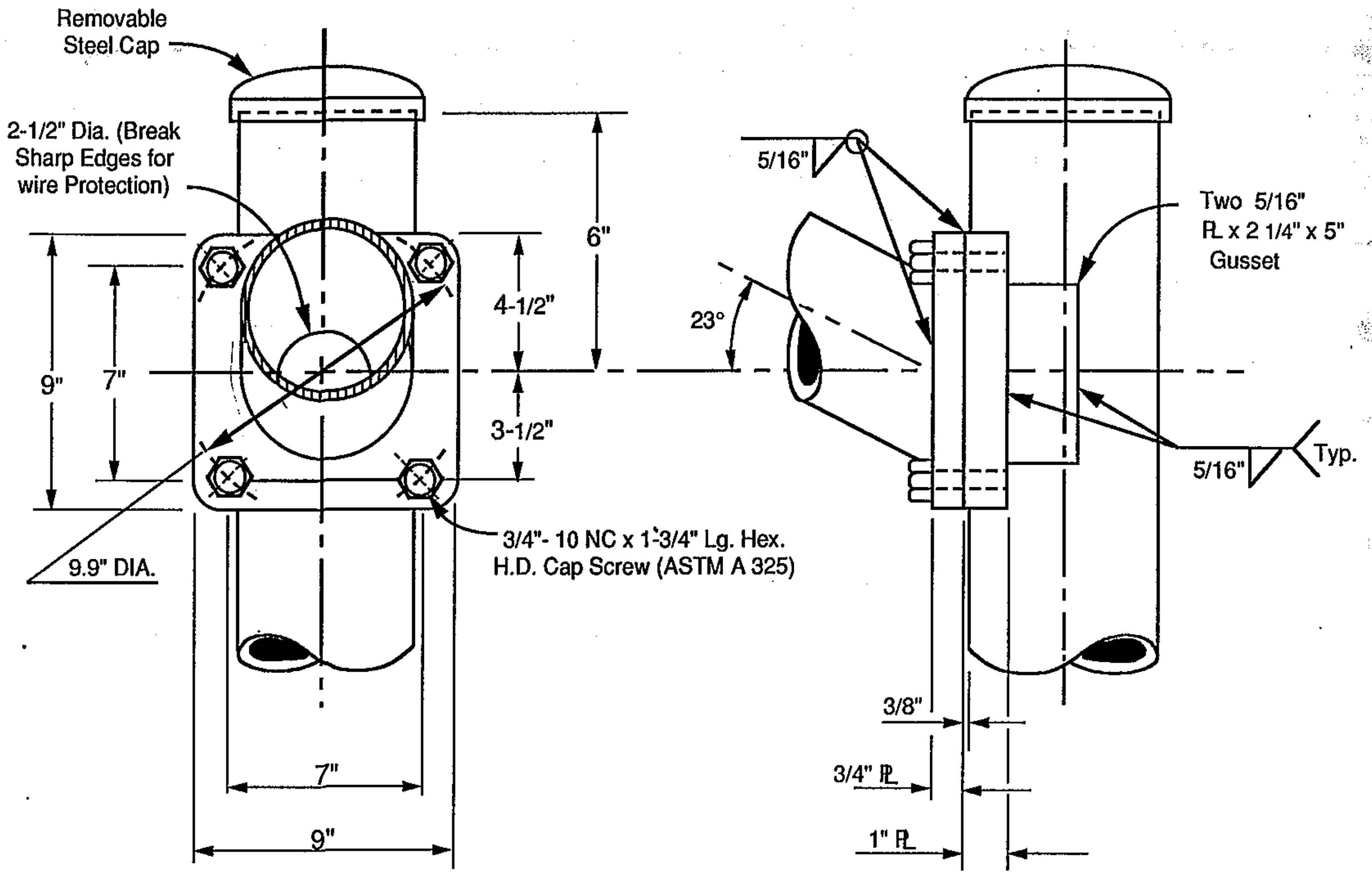


Figure 4 (Cont.). Base Plate Details



DETAIL B

Figure 4 (Cont.). Luminaire Arm Connection

Figures 5, and 6. The pole and the mast arm weighed 627 and 189 lb respectively. An ITT 400 watt luminaire with a high pressure sodium lamp weighing 49 lb was attached to the end of the mast arm, and it was wired with two No. 14 THW single strand copper wires to closely duplicate the full breakaway resistance. The total weight of the assembly without the parts which would remain behind when impact occurred was 883 lb.

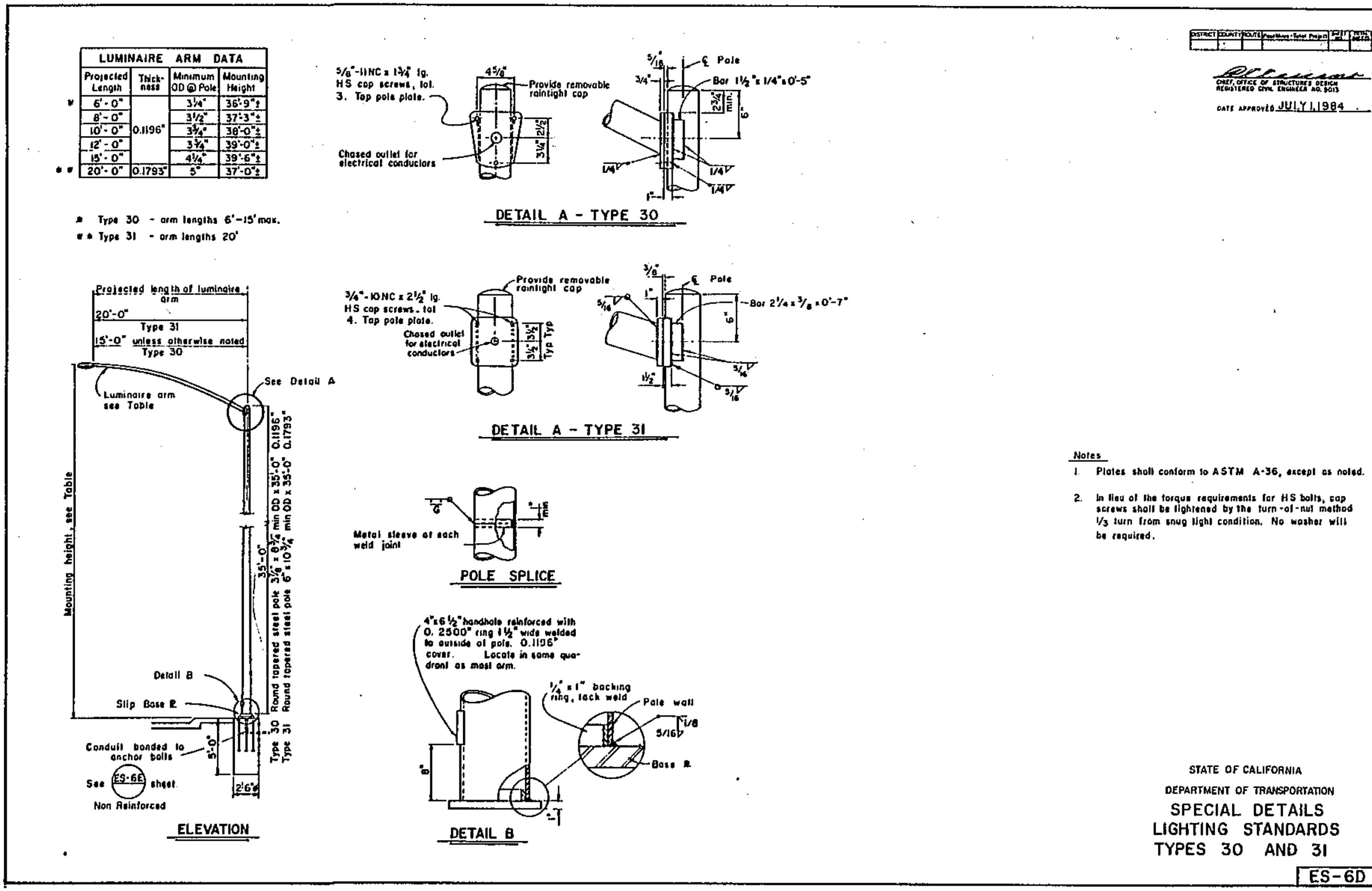
5.1.2.2 Breakaway Bases

Two types of breakaway devices were used in this study: the aluminum breakaway couplings and the standard Caltrans type 31 triangular slip base.

1 - Aluminum Couplings

As mentioned earlier, one of the objectives of the study was to find a simple breakaway device which requires less energy to initiate slip or fracture and in which the breakaway energy or slip characteristics would not change with time. Thus, it was decided to use aluminum couplings as the breakaway device because of their simple fracture type breakaway mechanism and the high probability that their breakaway energy would not increase with time.

Aluminum couplings manufactured by two different companies, ALCOA, and Transpo Industries, Inc. were considered for use. Both the ALCOA and the Transpo Industries couplings had previously been used by the Washington State Department of Transportation as breakaway devices. While both the ALCOA and the Transpo Industries



	Projected Length	Thickness	Minimum OD @ Pole	Mounting Height
*	6'-0"	0.1196"	3 1/4"	36'-9"±
	8'-0"		3 1/2"	37'-3"±
	10'-0"		3 3/4"	38'-0"±
	12'-0"		3 3/4"	39'-0"±
	15'-0"		4 1/4"	39'-6"±
**	20'-0"	0.1793"	5"	37'-0"±

Figure 5. Caltrans Types 30 and 31 Lighting Standards

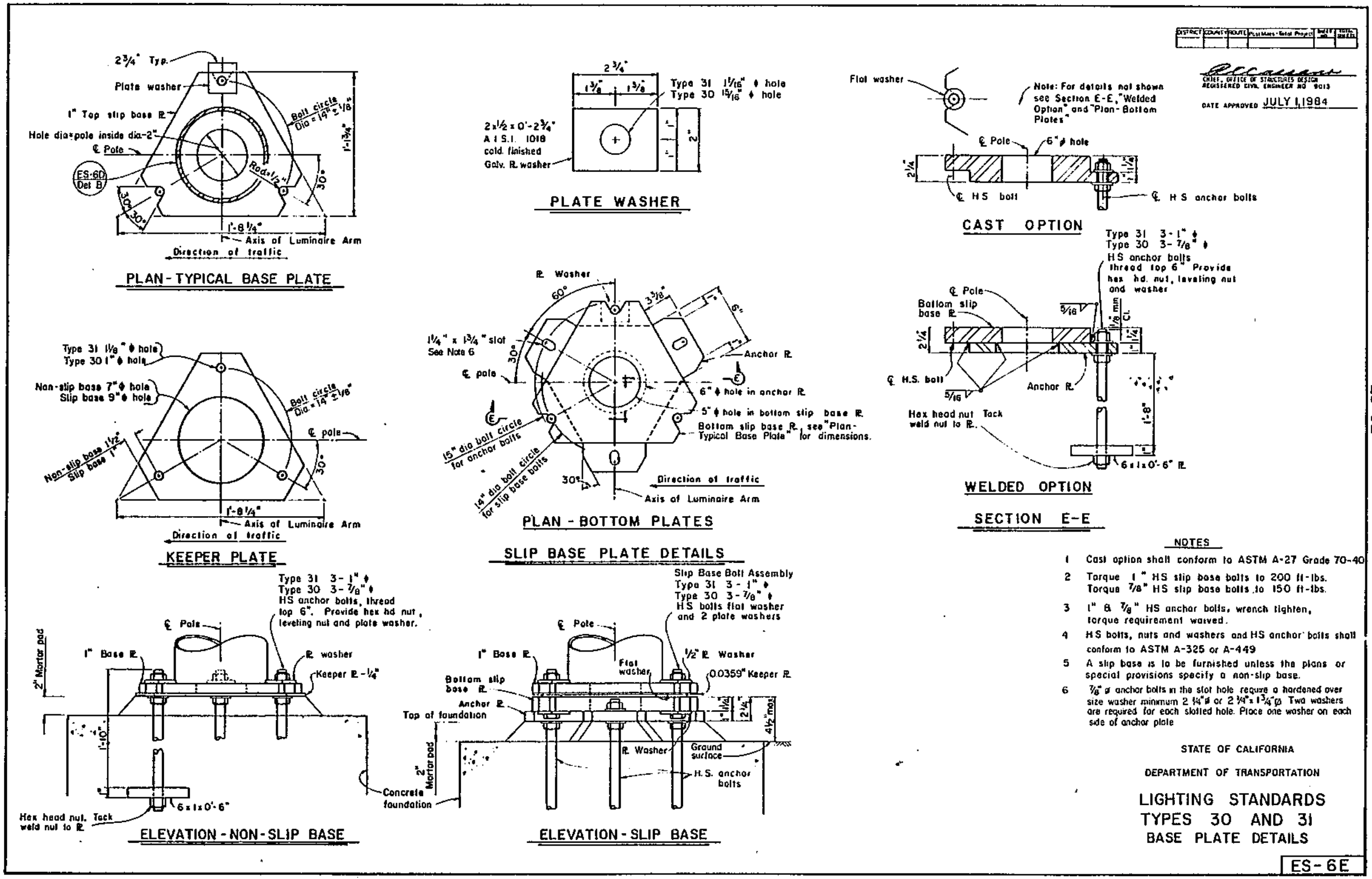


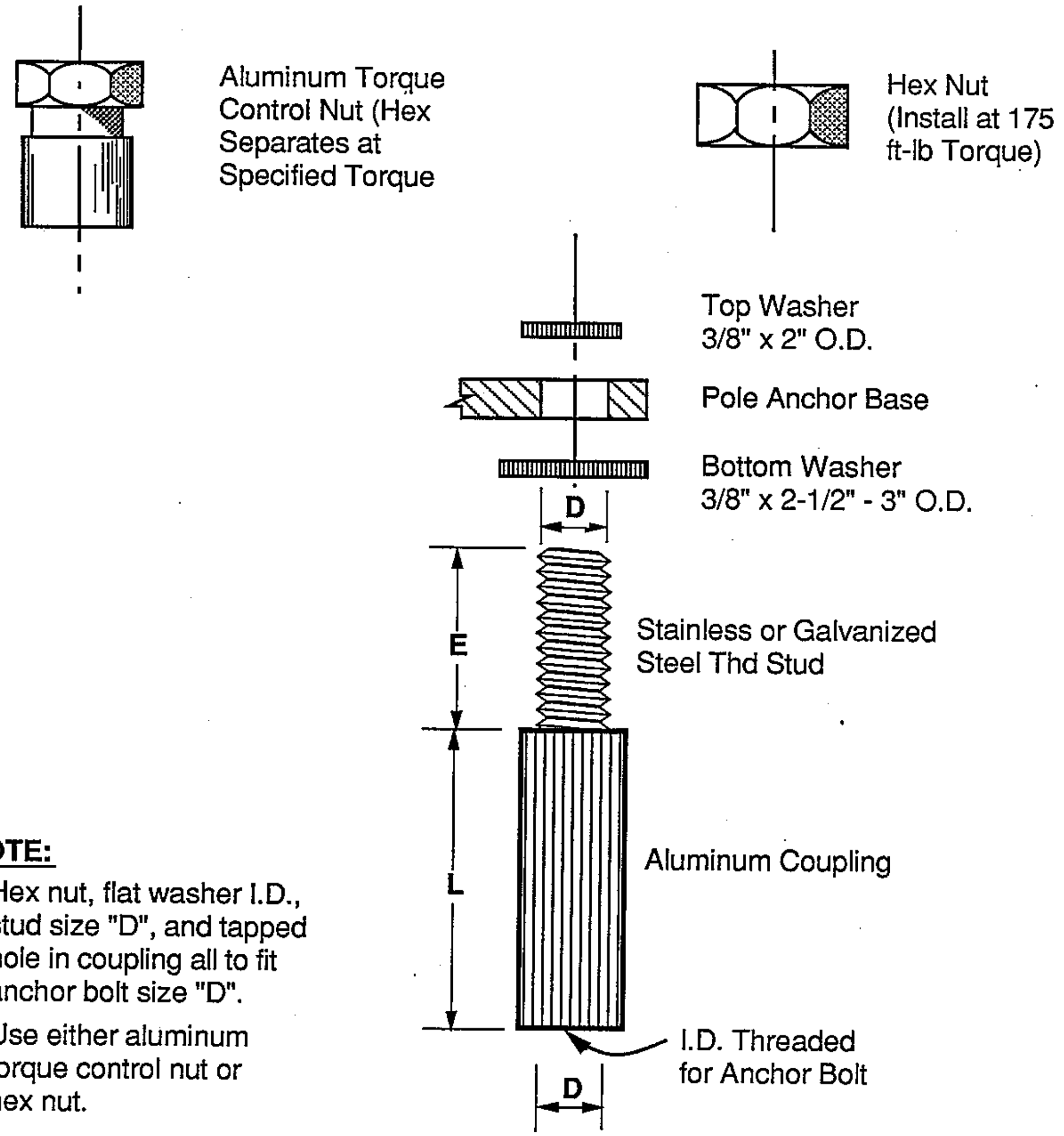
Figure 6. Base Plate Details - Caltrans Types 30 and 31 Lighting Standards

performed properly as safety (breakaway) devices, the ALCOA couplings had a history of bending or breaking most of the anchor bolts during impact. Due to the excessive cost of repairing or replacing the damaged anchor bolts, the use of ALCOA couplings was no longer approved as an acceptable breakaway coupling by Washington State Department of Transportation. This problem had also been experienced by two other states, and was addressed by FHWA in a letter of November 20, 1978, to the ALCOA management. So it was decided to use the aluminum coupling manufactured by Transpo Industries, Inc. which had been performing satisfactorily and was an approved breakaway coupling in the Washington State Department of Transportation.

The first two crash Tests, 401 and 402, were conducted using aluminum lighting standards equipped with the Transpo Industries die-cast aluminum couplings, Figure 7, as breakaway devices.

The eight couplings used in Tests 401 and 402 had been randomly selected from the 20 die-cast aluminum couplings obtained from Transpo Industries, Inc. No tensile or shear strength or chemical properties of the couplings had been determined prior to using them in crash Tests 401 and 402. Following the second crash test (Test 402), all pieces of the broken couplings were visually inspected. It was noted that five of the eight couplings had severe porosity defects (1/4" or larger holes) on the fractured surfaces, where coupling failure had occurred, Figure 8. It was also found that cases of Transpo coupling failures in the states of Utah and Wyoming had also been attributed to excessive porosity.

MOUNTING HEIGHT	DIMENSION TABLE			
	D	THD	E	L
30 - 50'	1"	8 NC	3-5/16" ± 1/16"	4-3/4"



NOTE:

Hex nut, flat washer I.D., stud size "D", and tapped hole in coupling all to fit anchor bolt size "D".

Use either aluminum torque control nut or hex nut.

Figure 7. Transpo Industries die-cast aluminum Coupling

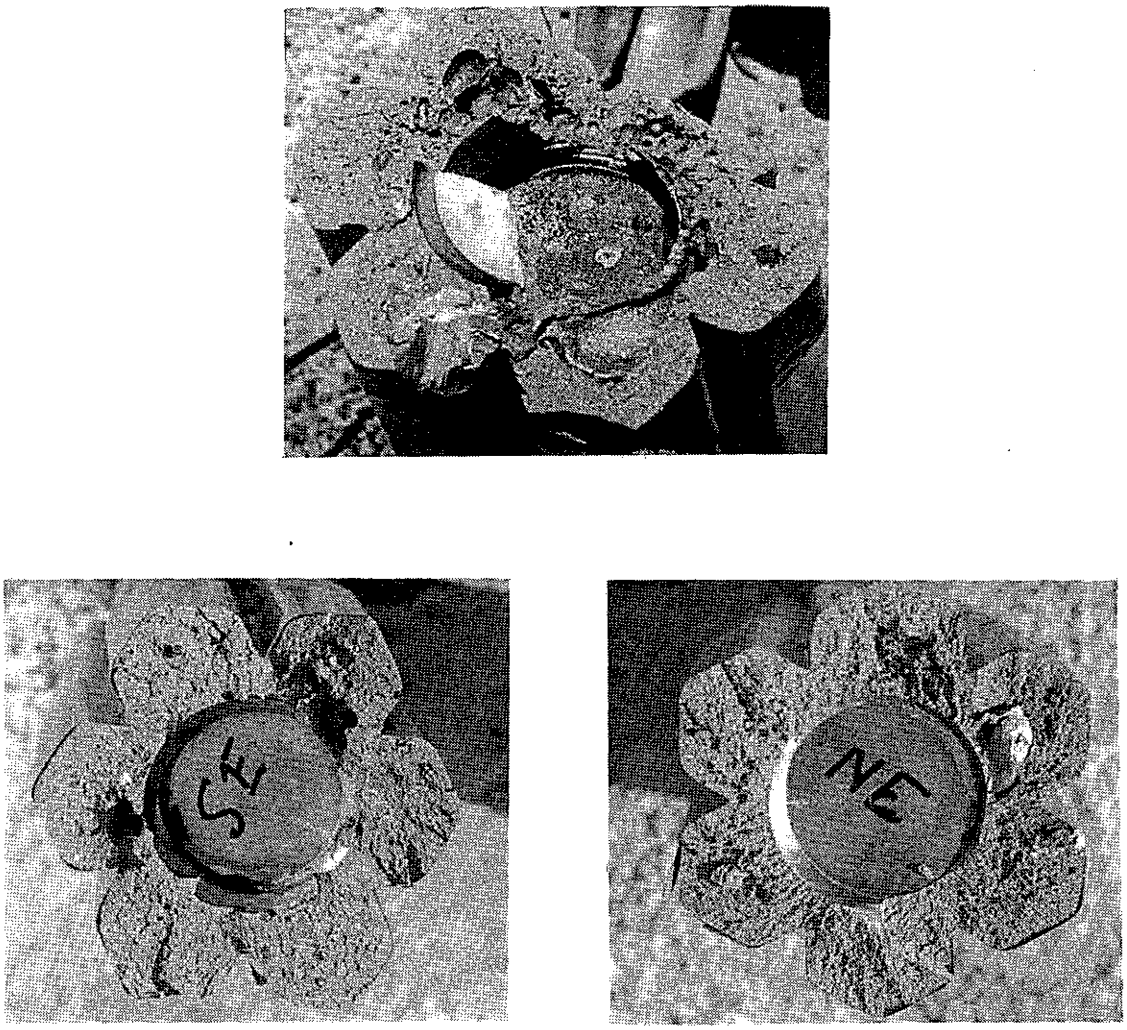


Figure 8. Fractured Surfaces of Transpo Die-Cast Aluminum Couplings Used in Tests 401 and 402

Two couplings (from the remaining twelve) were tested in axial fatigue. Each specimen was cycled sinusoidally from -2000 to +7500 lb for over two million cycles. There was no coupling or thread failure.

In an attempt to find four couplings with an acceptable level of porosity for the next test (Test 403), it was decided to x ray the remaining couplings. In addition, the ten tested couplings (8 broken couplings from crash tests and 2 which had been tested for fatigue) were also x rayed. Good quality x rays were taken by the Industrial Testing International, Inc. in Sacramento, California. It was found that all of the 20 couplings from the original lot (lot # 3222) exceeded the worst defects level, level 4, as defined in ASTM E505, category A, reference radiographs (1).

The manufacturer of the couplings, Transpo Industries Inc. was then contacted and notified that all of the 20 couplings which had been sent for use in crash tests were rejected and could not be used in further crash tests. They were also notified that only couplings of level 3 quality or better (as per ASTM E505 reference radiographs for 5/8 in. thickness) would be accepted for future crash tests.

In response, Transpo Industries sent 11 couplings from a new lot (lot #3558) were delivered to the Translab with x rays taken by Alpha Testing Laboratories, Inc. in Totowa, New Jersey. All the couplings x rayed were reported as passing the ASTM E505 level 3 defect severity; however, the x rays were of a very poor quality and were retaken by Industrial Testing International, Inc. The new x rays showed that one of the 11 couplings (# 8) had porosity defects exceeding level 4, and was rejected. Four couplings (numbers 3, 5, 9, and 11 from lot 3558) with level 2 porosity defects were selected and used in Test 403.

However, due to these continued defects, failure to meet the current specifications, and the fact that this had already caused a delay in the planned progress of the project, it was decided not to accept or use any new couplings made by Transpo Industries, Inc. until they correct their problem and establish a comprehensive quality control program.

Transpo Industries, Inc. was notified of the decision. In February, 1984, a set of 14 couplings from a new lot, No. 210, was sent to the Translab. Quality assurance tests, including tensile, restrained shear, and fatigue tests were conducted at the Translab. Also radiographic evaluations were performed by Industrial Testing International, Inc. It was found that the couplings did not comply with the Caltrans specifications and corrective measures made by Transpo Industries, though they had helped considerably, had not yet solved the problem completely. Thus, based on the test results from these couplings and those from the two previous lots, the Transpo couplings were rejected for further use in the study as well as general use by Caltrans.

A series of specification compliance tests were also performed on 16 model 100-1 ALCOA extruded aluminum breakaway couplings from lot 096 05100 (manufactured in August 1984) at the Translab. Tests included dimensional checks, direct tension, restrained shear, cyclic loading (fatigue tests), and corrosion evaluation in the salt fog chamber. Although the couplings passed the ultimate tensile strength tests, they did not pass either the restrained shear tests or dimensional checks. Two out of three couplings also failed the fatigue tests. Based on these test results, the ALCOA couplings were also rejected for further use in this project. About this time we were notified that ALCOA was redesigning their old coupling and were doing developmental testing. After much delay and waiting, we were notified that ALCOA had discontinued manufacturing their couplings.

The standard Caltrans type 31 triangular slip bases were used in crash Tests 404, 405, 406, and 407. The results regarding the x rays and static tests of aluminum couplings are given in section 5.2.8.

2- Standard Type 31 Triangular Slip Base

The slip base used with the Caltrans type 31 and the modified type 31 lighting standards as detailed in the 1984 California Standard Plans, ES-6E, is shown in Figure 6. The top base plate consists of a 1-in.-thick triangular steel plate welded to the bottom of the pole and the bottom base plate assembly consists of two quasi-triangular steel plates rotated 60 degrees from each other and welded together. The bottom base plate attaches to the foundation with three 1-in.-diameter high strength anchor bars cast into the concrete foundation with a bolt circle diameter of 15 in.

The top and bottom base plates are clamped together with three 1-in.-diameter A325 galvanized bolts having a bolt circle diameter of 14 in. Correct location of the various parts and proper torquing of the clamping bolts is critical in making the breakaway base function properly. Figure 14 shows the assembled slip base as used in the crash tests.

5.1.3 Installation Procedures - Breakaway Lighting Standards

5.1.3.1 Lighting Standards with Aluminum Breakaway Couplings

The aluminum lighting standards used in Tests 401 and 402 and the modified Caltrans type 31 steel lighting standard used in Test 403 were each equipped with four 1-in.-diameter aluminum breakaway couplings. The lighting standards were assembled and installed by a Caltrans district 3 maintenance crew on the concrete foundations already cast in place.

1- Aluminum Lighting Standards

First, the truss mast arm was bolted to the pole on the ground. Four 1/2-in.-diameter X 4-in. stainless steel bolts were used and the bolts were torqued to 50 ft-lb. To simulate the field conditions, a luminaire was attached to the end of the mast arm and it was wired using 2 No. 14 TH wires. The wires ran from the luminaire down through the mast arm and pole and then through a "U" shaped conduit already cast into the foundation. A fuse connector was crimped onto the end of the two wires outside the foundation base.

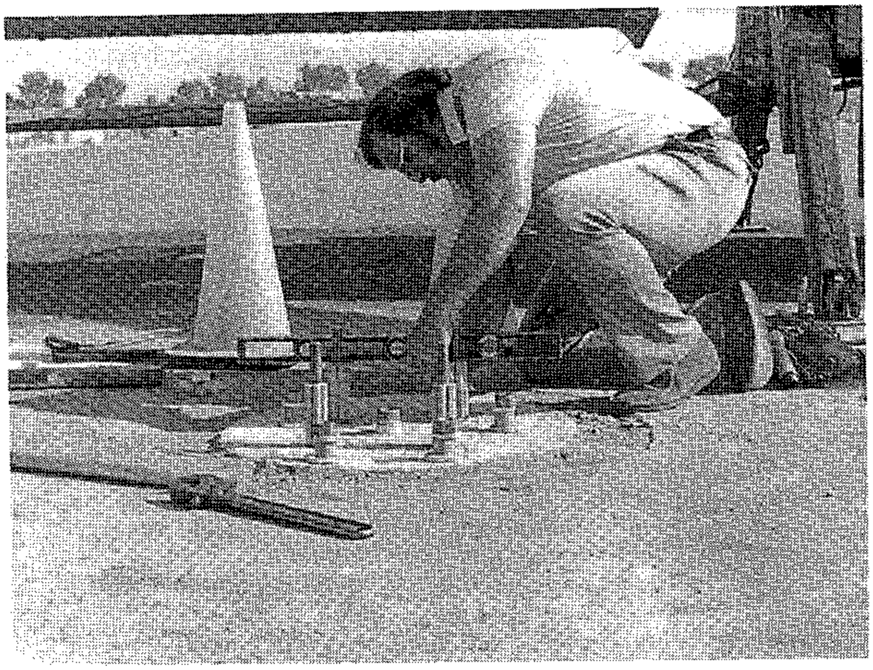
A sharp 2-ft-long scribe rod was anchored into the asphalt pavement with concrete nails about 2 ft from the down stream side of the lighting pole, so that any relative movement of the concrete foundation with respect to the surrounding ground could be determined. A small flat steel plate on which the scribe tip was placed, was epoxied to the face of the foundation. It was painted white and then flat black, so that any movement of the tip of the scribe pointer could be easily seen.

Four die cast aluminum couplings (made by Transpo Industries, Inc.) were then installed on the foundation anchor bolts (14-1/2" bolt circle diameter) and were leveled, Figure 9.

Next, the pole and mast arm were erected as a unit and lifted with a sling at the balance point by a mobile crane. While the pole and mast arm hung suspended over the foundation, the pole was lowered such that the four coupling studs passed through the four holes on the shaft base plate. The top washers were installed and nuts were then screwed onto the coupling studs and were torqued to 175 ft-lb. Installation of a lighting standard with aluminum breakaway couplings is shown in Figure 10.

<u>2- Modified Caltrans Type 31 Steel Lighting Standard</u>

A modified Caltrans type 31 steel lighting standard with aluminum breakaway couplings was used in Test 403. The foundation used in this test had previously been used for Test 401. To reuse the foundation, the two anchor bar studs which had previously been bent in Test 401 were carefully straightened by cold bending. The



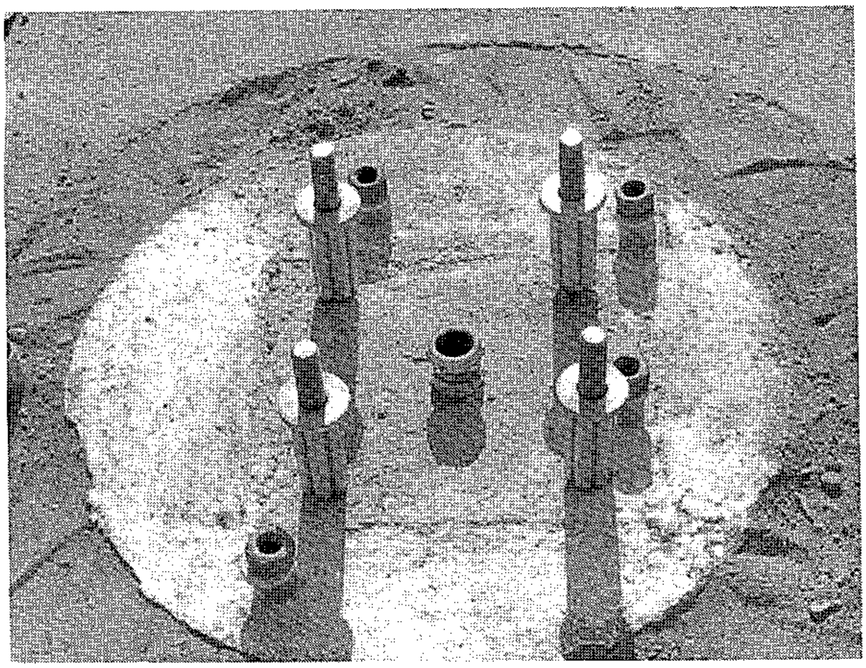
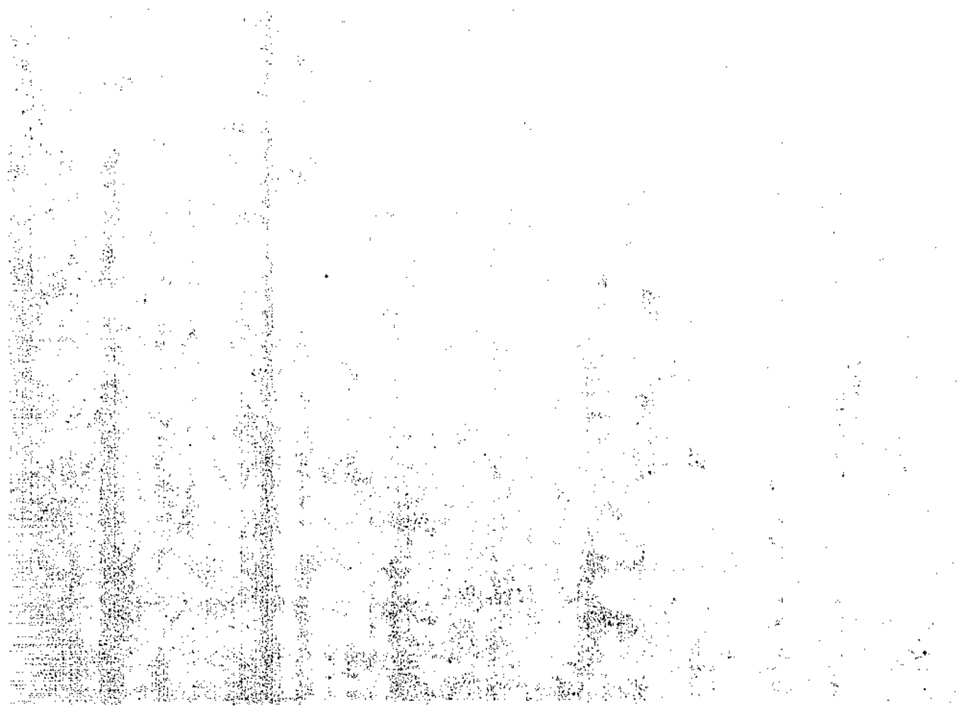


Figure 9. Installation of Die-Cast Aluminum Couplings on the Foundations Anchor Bolts



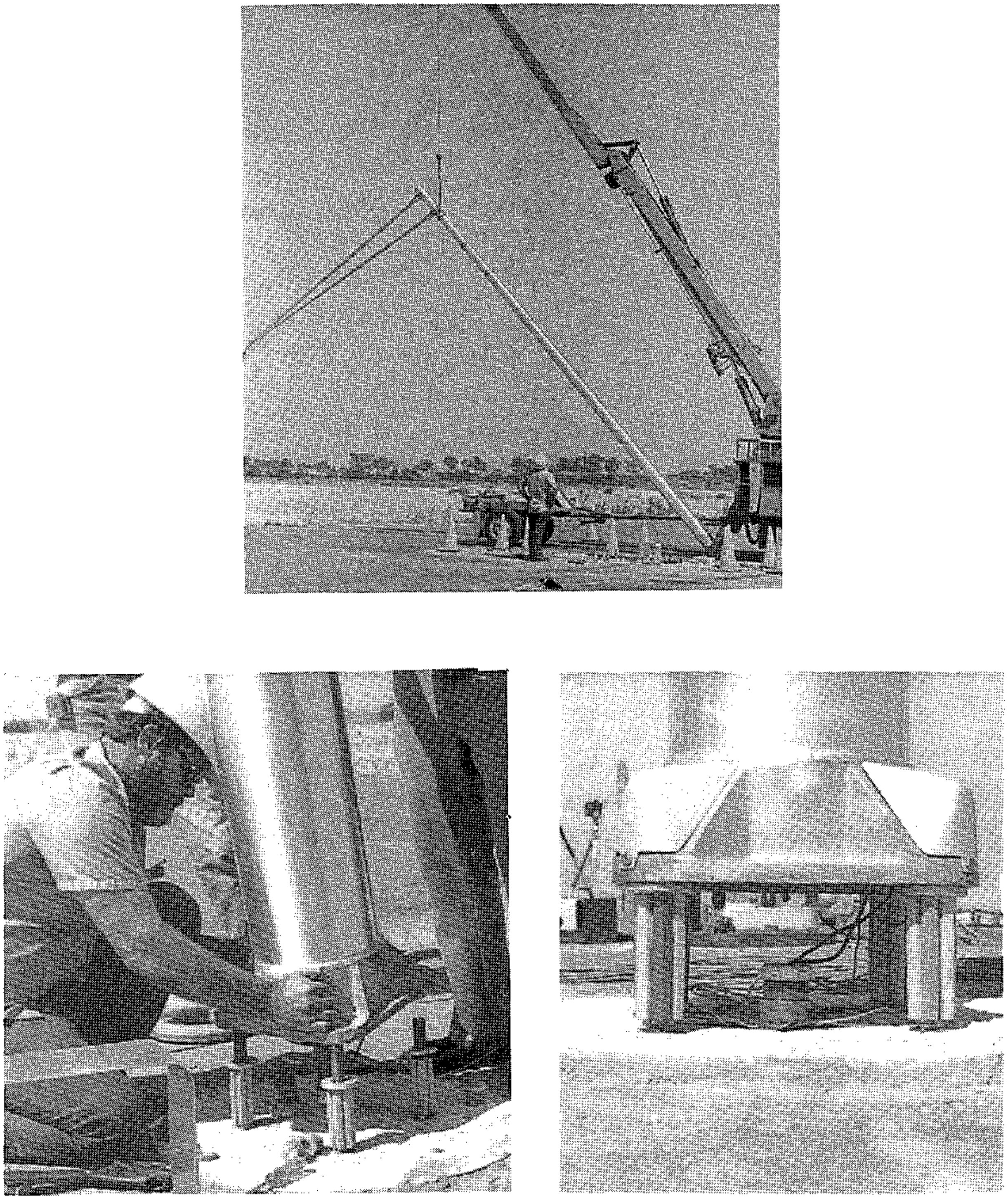


Figure 10. Installation of Lighting Standard with Aluminum Couplings

installation procedure for this lighting standard (Test 403) was similar to that explained before for Tests 401 and 402. The mast arm, however, was installed by tightening four 3/4-in.-diameter X 1-3/4 in. high strength cap screws to 1/4 turn past snug tight. As the grip length (mast arm plate thickness) was only 3/4 in., and the torque on the cap screws at snug plus 1/4 turns was extremely high, the cap screws were not tightened the full 1/3 turn past snug tight as required in the standard plans.

5.1.3.2 Standard Type 31 and Modified Type 31 Steel Lighting Standards with Triangular Slip Bases

A standard Caltrans type 31 steel lighting standard equipped with a triangular slip base was used in Test 404. The pole and mast arm were assembled and erected by a District 3 maintenance crew. The 20-ft mast arm and 35-ft-long pole conformed to requirements as shown in the 1984 Caltrans Standard Plans ES-6D and ES-6E, Figures 5 and 6. The mast arm was bolted to the pole on the ground with four 3/4-in. cap screws and tightened 1/3 turn past snug tight. A luminaire was then installed at the end of the mast arm, and electrical wires were run inside the pole and the mast arm to simulate the field conditions as closely as possible. A new foundation having three 1-in.-diameter high strength anchor bars, as required for a standard Caltrans type 31 lighting standard, was used. The anchor bars were oriented (with respect to the crash car direction) so that breakaway energy of the slip base, when impacted by the crash car, would be maximum as required by NCHRP Report 230.

To obtain this maximum breakaway energy, the approach direction of the crash car was adjusted to hit one of the three clamping bolts head-on, Figure 11. At this critical approach direction, the 60-degree angle formed by this head clamping bolt and the other two back ones is bisected.

The pole and mast arm were erected as a unit and lifted with a sling at the balance point (approximately 2 ft out on the mast arm) by a mobile crane. While the pole and mast arm hung suspended over the anchor bars, the lower base plate, which had been leveled on the anchor bolts, was secured to the upper pole plate using required plate washers and clamping bolts. Nuts used on the 1 in clamping bolts were lubricated with teflon spray and each was torqued to 200 ft-lb, while the weight of the pole and mast arm were still suspended by the crane. Then the assembled lighting standard was lowered over the anchor bars and onto the leveling nuts. The top nuts on the anchor bars were installed and initially finger tightened. The pole was then released and anchor bar nuts were wrench tightened as specified in the 1984 Standard Plans (23). Stiff mortar was then packed under the lower slip base plate forming a pad under the bottom plate of the slip base.

As a check on clamping bolt tensions, the length of the clamping bolts were measured before and after installation and elongation of the clamping bolts were determined. The tension in each bolt was then determined from Figure 12, tension versus elongation for similar bolts (same grip length as the field grip length) obtained from direct tension tests. Tension in each bolt

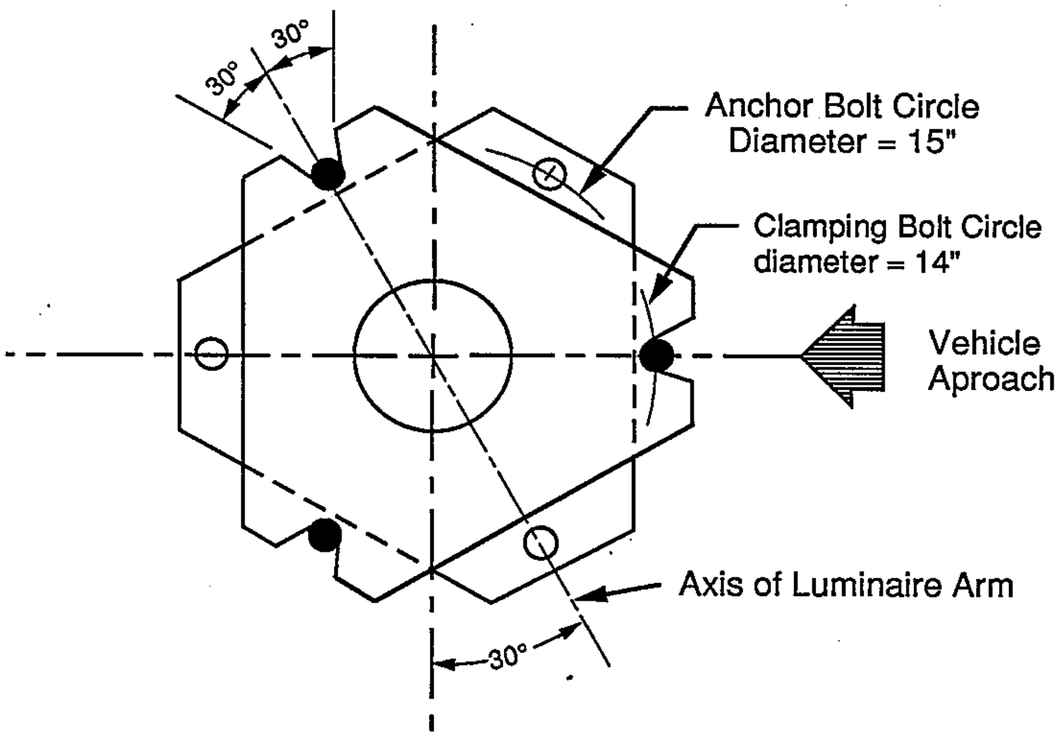


Figure 11. Orientation of Type 31 Triangular Slip Base Used in Tests 404, 405, 406, and 407

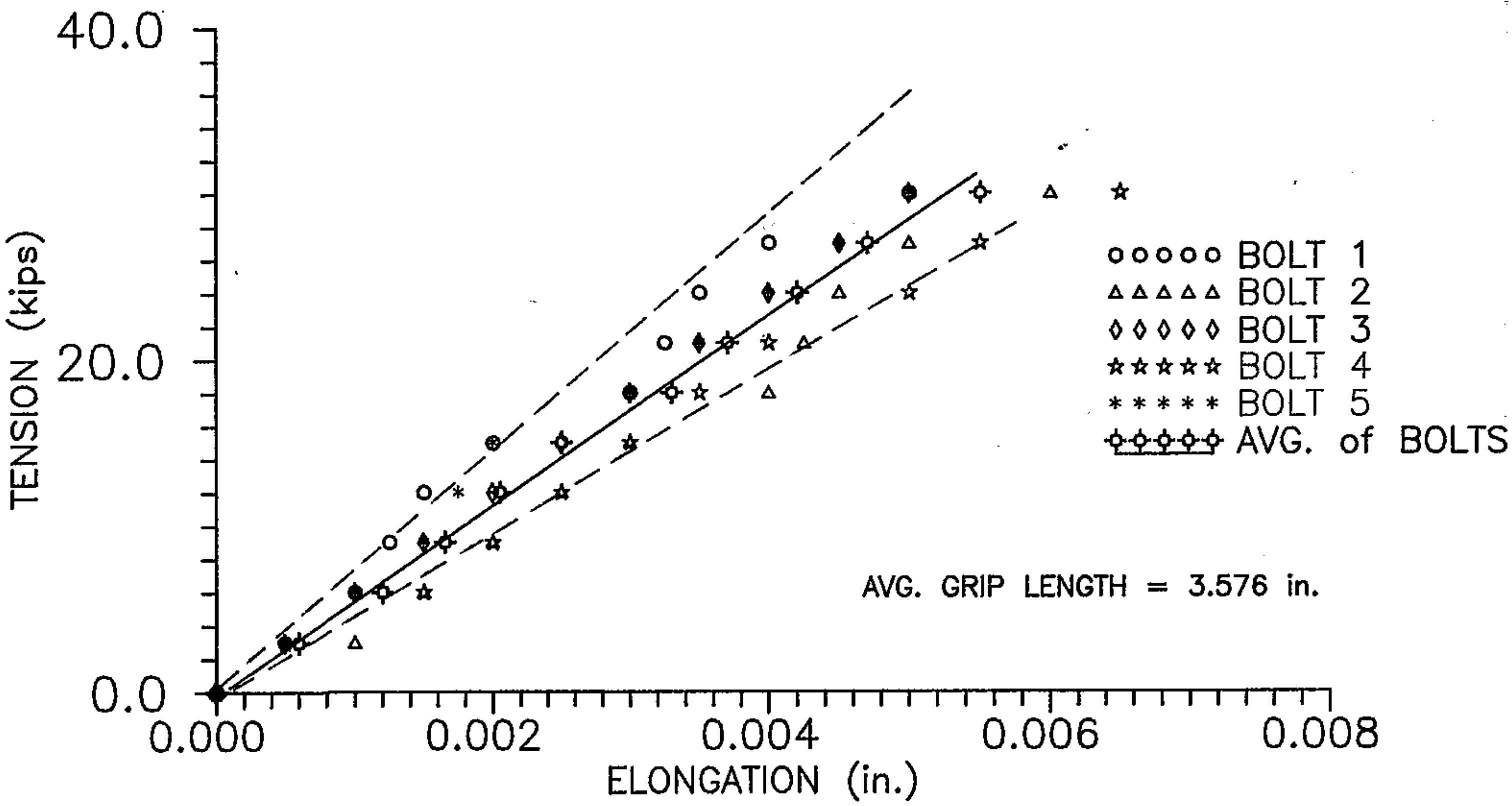


Figure 12. Tension vs. Elongation for A–325 Galvanized 1-in.-dia. x 5 in. Bolts in Elastic Range.

was also determined from the torque versus tension of similar galvanized clamping bolts (Figure 13) evaluated in laboratory testing performed during a previous research project. Table 1 compares the tension in the bolts as determined from measuring elongation of the bolts (Figure 12) with those obtained from applied torque, Figure 13. Figure 14 shows the triangular slip base as used in Tests 404 and 405.

Since the lighting standard used in Test 404 was undamaged, it was reused in Test 405. The foundation used in Test 404 was also used for Test 405. Installation procedure was similar to Test 404; however, since there was already a grout pad under the slip base bottom plate from Test 404, there was no need to place new mortar under the base plate.

Installation procedures for the modified Caltrans type 31 lighting standards used in Tests 406 and 407 were the same as Tests 404 and 405. Also the foundation used in Tests 404 and 405 was used for Tests 406 and 407 .

5.1.4 Test Vehicles

Seven 1979 Honda Civic 2-door sedans were used for seven crash tests. The vehicles had automatic transmissions, front mounted engines, and were front wheel drive. For each test, the vehicle was in good condition and free of major body damage and missing parts. All equipment on the vehicles was standard. Thus, all vehicles complied with the requirements of NCHRP Report 230. Figure A1 in

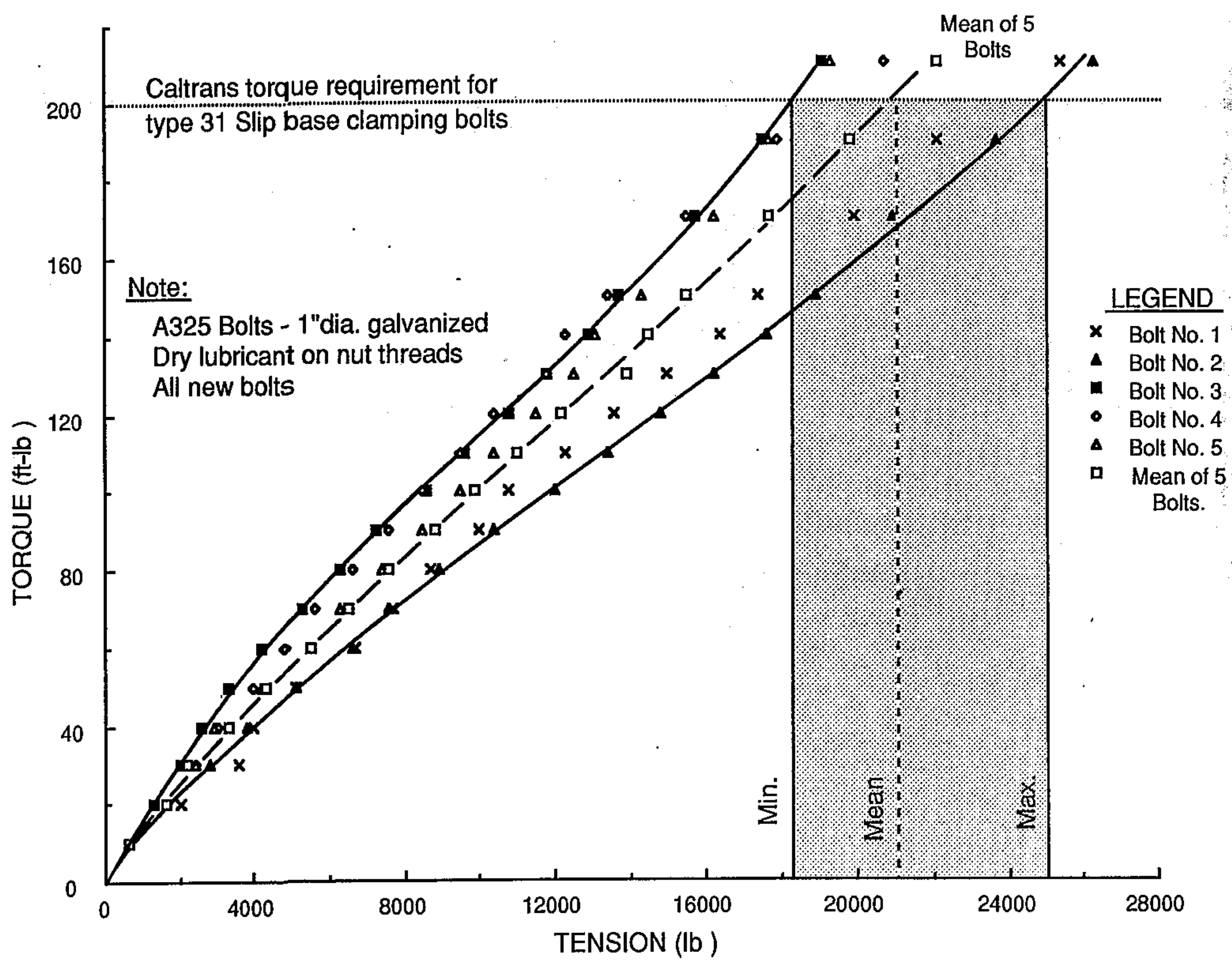


Figure 13. Torque vs. Tension For A 325 Galvanized 1-in-dia x 5 in. Bolts

Table 1. Comparison of slip base clamping bolt tension obtained from field measurements and laboratory tension tests

Test No.	Bolt No.	Bolt Elongation Due to 200 ft-lb Torque (in.)	Bolt Tension (kips)	
			Torque vs. Tension Figure 13	Tensile Tests Figure 12
404	1	0.0017	18.2-25	8.2-12.2
	2	0.0021	18.2-25	10.1-15.1
	3	0.0022	18.2-25	10.6-15.8
405	1	0.0024	18.2-25	11.5-17.3
	2	0.0017	18.2-25	8.2-12.2
	3	0.0018	18.2-25	8.6-13
406	1	0.0032	18.2-25	15.4-23
	2	0.0026	18.2-25	12.5-18.7
	3	0.0040	18.2-25	19.2-28.8
407	1	0.0032	18.2-25	15.4-23
	2	0.0010	18.2-25	4.8-7.2
	3	0.0022	18.2-25	10.6-15.8

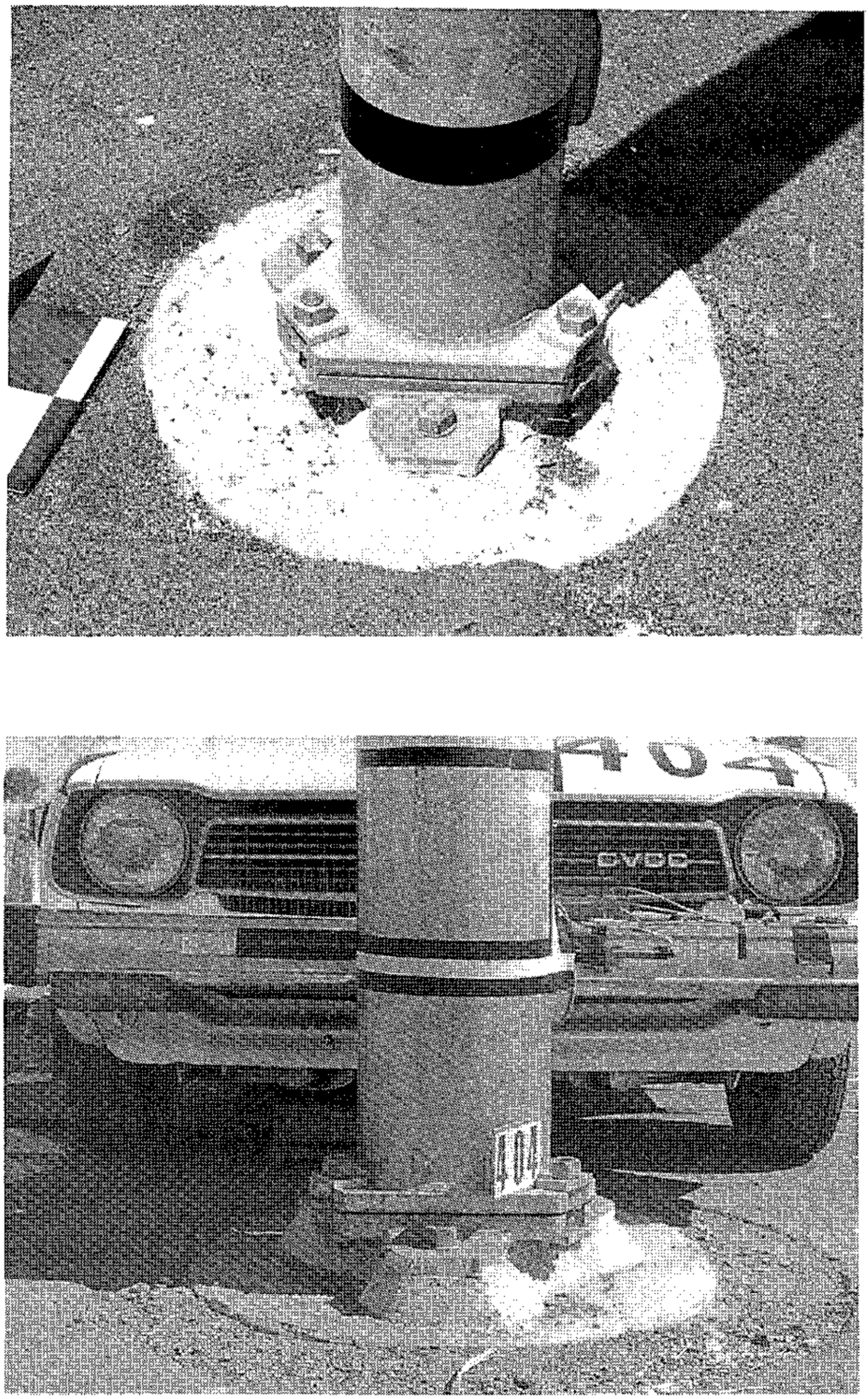


Figure 14. View of Triangular Slip Base Used with Caltrans Type 31 and Modified Type 31 Lighting Standards

Appendix A shows the vehicle dimensions.

The test inertia weight of the vehicle (weight of vehicle and all items and test instruments rigidly attached to the vehicle structure; weight of dummies irrespective of the degree of restraint is not included) was 1850+50 lb. The gross static weight of the vehicle including the 165-lb dummy was 2015+50. The exact weight of each vehicle is given in table D1 (Appendix D).

The vehicles were self-powered. A speed control device maintained the desired impact speed once it was reached, and a contact switch mounted under the front bumper opened the ignition circuit and cut the vehicle engine just before the impact. Guidance of the vehicle was achieved with a cable anchored at both ends of the vehicle path and passing through a guide bracket bolted to the spindle of the front wheel. A steel knockoff bracket released the guide bracket just prior to the impact. No constraint was put on the steering wheel. Remote braking was possible after the impact or for emergency situations at any other time.

A detailed description of the test vehicle equipment and guidance system is given in Appendix A.

5.1.5 Data Acquisition Systems

Test data were recorded by both high speed motion picture cameras and electronic instrumentation.

Several high speed movie cameras, and two sequence cameras located around the impact area were used to record the impact phase of each crash test. The test vehicles and the lighting standards were also photographed before, during and after impact with a normal speed movie camera and still cameras. All cameras were mounted on tripods except one high speed camera which was mounted in the test vehicle to record the dummy's motion, and two high speed cameras which were mounted on a tower close to the lighting standard and aimed at the impact point. Data from the high speed movies were reduced on a Vanguard Analyzer. A film report of this project has been assembled using edited portions of the movie coverage.

Three accelerometers were mounted on the floor of the vehicle in the passenger compartment at the center of gravity to measure longitudinal, lateral, and vertical acceleration. Also three rate gyro transducers were mounted on the floor of the vehicle (close to the accelerometers) to measure the roll, pitch, and yaw of the vehicle after impact. The accelerometer data were used to judge occupant risk during impact.

An anthropomorphic dummy with a triaxial accelerometer mounted in the head cavity was placed in the driver's seat of the test vehicle with no restraint. The dummy, "Willie Makit" a part 572 dummy built to conform to the Federal Motor Vehicle Safety Standards by the Sierra Engineering Company, was a 50th percentile American male weighing 165 lb. A high speed camera mounted in the vehicle recorded the dummy's motion, and the triaxial accelerometer recorded the longitudinal, lateral, and vertical accelerations of the dummy's head during impact. The accelerometer data were then used to calculate the Head Injury Criterion.

A sliding weight device was mounted on the right side of the vehicle's roof. Upon impact, the weight fitted with ball bearings, slid two feet forward on a smooth rod. The "rattle space" time, the time required for the weight to slide two feet forward after impact, was measured from the high speed movie film. If for any reason the accelerometer data failed, this could be used as a rough measure of the occupant/compartment impact velocity (O/CIV).

A detailed description of the photographic and electronic instrumentation, camera arrangement, data collection and reduction techniques, accelerometer data, and film data plots are given in Appendices B and C.

5.1.6 Test Procedures for X Rays and Static Tests of Aluminum Breakaway Couplings

5.1.6.1 X rays

After observing excessive amounts of porosity in broken pieces of die-cast aluminum couplings manufactured by Transpo Industries Inc., the couplings were x rayed to determine if they had an acceptable porosity level. The x rays were taken by Industrial Testing International, Inc. in Sacramento, California. 0 and 90 degrees x rays were taken of each coupling and they were then classified according to the porosity and shrinkage defect levels for 5/8-in.-thick sections shown in ASTM E505 reference radiographs (1). The results are given in Table 2, section 5.2.8.1.

5.1.6.2 Static Tests

A set of specification compliance tests were performed on both, the Transpo die-cast aluminum couplings and the ALCOA extruded aluminum couplings. Tests were performed at the Translab as follows:

1- Dimensional Checks

The coupling's dimensions were measured (Table 3, section 5.2.8.2) and compared with the current Caltrans specifications.

2- Tensile Tests

The tensile strength of aluminum breakaway couplings was determined by subjecting a full-sized coupling specimen to a uniaxial tensile load using a universal testing machine. The load was gradually increased at a constant stroke rate of 0.5 in. per minute until failure occurred.

Test Specimen

The test specimen consisted of one aluminum breakaway coupling and one 8-in.-long, ASTM A307 hot-dip galvanized anchor bar (with 4 in. of 1 in.-8 UNC thread, class 2A before galvanizing, on one end) per test. A typical aluminum breakaway coupling for tensile testing is shown in Figure 15.

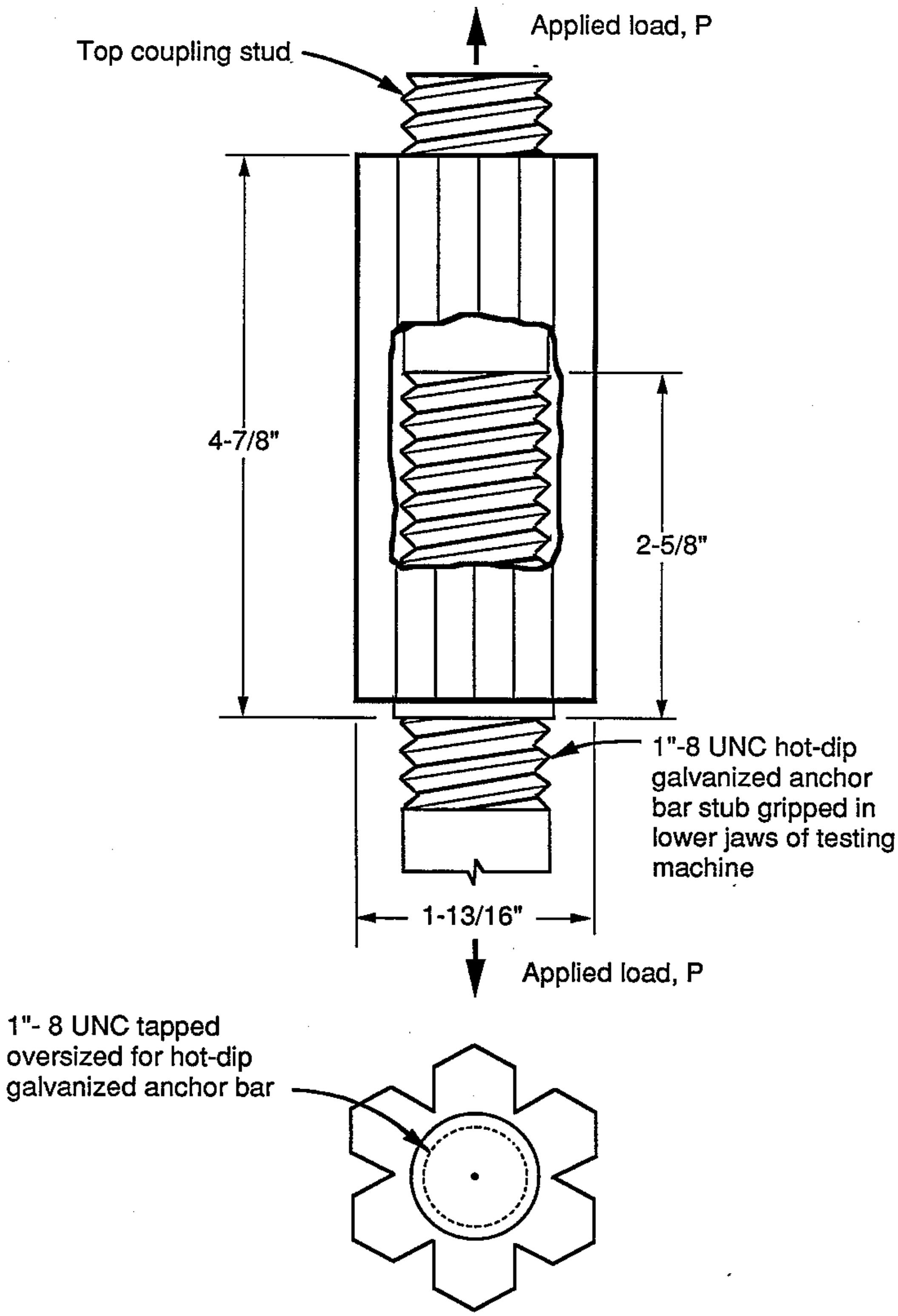


Figure 15. Test Fixture for Determining Tensile Strength of Aluminum Couplings

Test Procedure:

First the universal testing machine was set to an appropriate load scale (up to 35 kips of tensile load) and the needle indicator was set to zero.

The top nut and two washers from the top stud of the coupling were removed (only the upper washer was removed if the large lower washer was glued in place, ALCOA). Then, the anchor bar was screwed into the female threads inside the bottom end of the coupling until the bar was engaged into the coupling body the correct amount (2-5/8 in. for Transpo or ALCOA couplings).

Next, with the unthreaded shank of the anchor bar pointing downward, the stud protruding from the top of the coupling was screwed into the 1-in. mandrel gripped in the upper crosshead of the test machine. While lowering the upper platen, the anchor bar was guided into the lower grip of the testing machine and then it was firmly grasped with the jaws located in the lower grip. Finally, the upper crosshead was locked into place.

The tensile load was then applied at a constant head speed of 0.5 in. per minute until the coupling fractured. At this time, the ultimate tensile strength of the coupling, mode of failure, and any defects observed on the fractured surface were recorded. Figures 16-a and 16-b show the test setup and the fractured sample respectively. Tables 4 and 5 in section 5.2.8.2 show the summary of tensile test results.

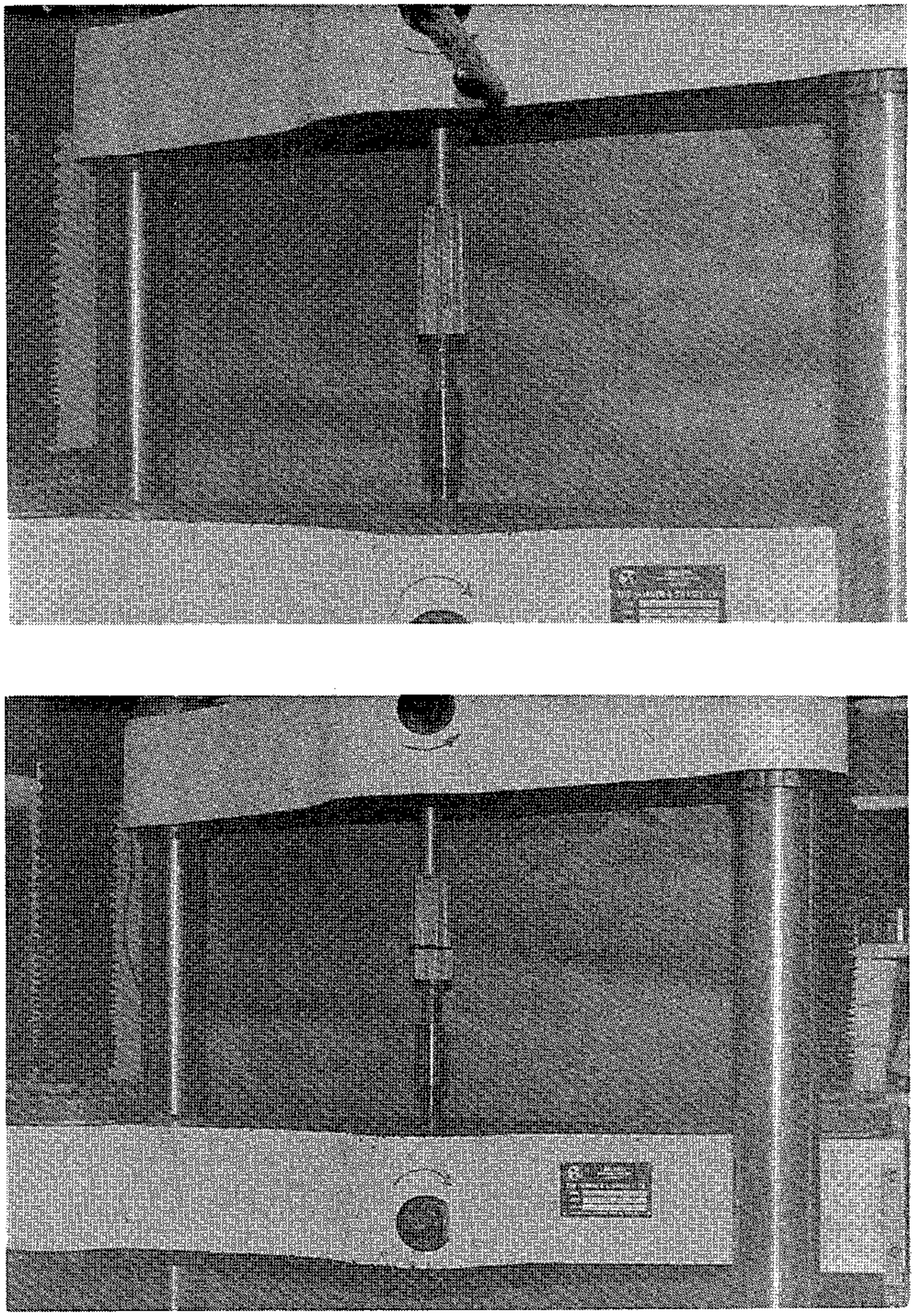


Figure 16. Tensile Test Setup and Typical Failure Mode of Transpo Die-Cast Aluminum Couplings

3- Restrained Shear Test

The shear strength of pairs of aluminum breakaway couplings when they are restrained, as when installed at the base of a lighting standard was determined by subjecting a pair of couplings to shear loading. A special "L" shaped testing frame, Figure 17, was made for this test and the load was applied using a universal testing machine. The load was applied at a rate of 0.5 in. per minute until failure occurred.

Test Specimen

The test specimen consisted of two aluminum breakaway couplings, two 5-in.-long ASTM A307 hot-dip galvanized anchor bar stubs (1 in.-8 UNC threads, class 2A before galvanizing), and two hex nuts tapped oversize to fit the above anchor bars (class 2B fit) for each test.

Test Procedure:

The L-shaped test fixture, Figure 17, was placed on the testing machine's loading platen so that the small locater pin in the bottom of the fixture positioned into the hole at center of the loading platen. At this position, the loading bar is aligned along the load axis of the testing machine.

The two 1-in.-diameter by 5-in.-long, galvanized ASTM A307 threaded studs were then screwed into the holes on the vertical leg of the restrained shear test fixture and the two galvanized hex nuts were screwed onto the outside ends of the two anchor bar

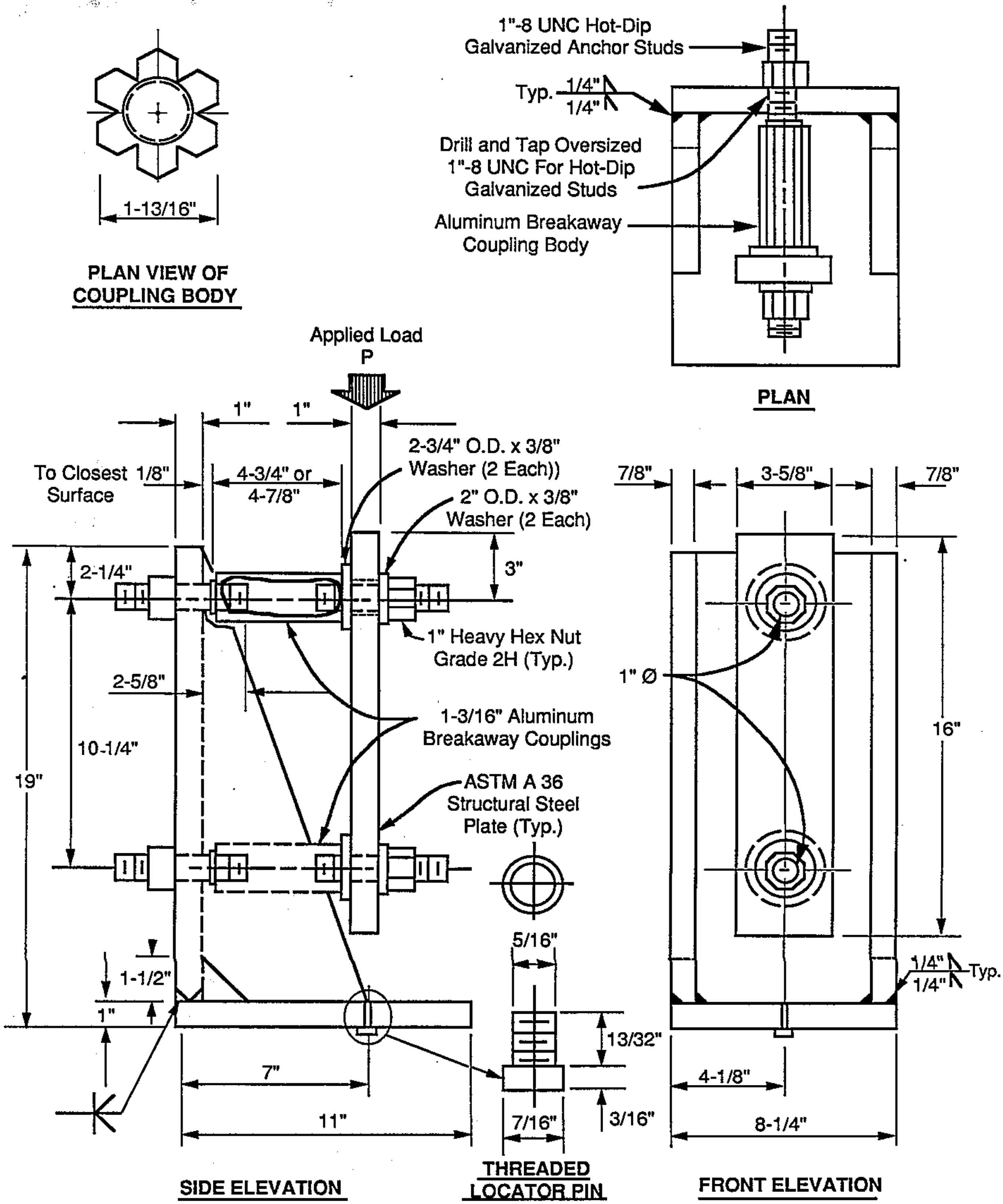


Figure 17. Test Fixture for Determining Restrained Shear Strength of Aluminum Couplings

studs. Each nut was tightened to 250 ft-lb of torque against the outside face of the test fixture.

Next, the two coupling bodies were screwed the proper distance onto the anchor bar studs (2-5/8 in. for the Transpo and ALCOA couplings). A 1/4-in.-clear gap was left between the bottom of the coupling and the inside vertical face of the test fixture.

Holes in the 1-in.-thick loading plate were then centered on the top studs of the couplings bearing against the larger washers already positioned onto the coupling studs. While keeping the loading plate holes centered on the top studs, the small washers and the top nuts were replaced and gently tightened. A carpenter's level was used to make sure that the loading plate was vertical. Each top nut was initially tightened to a 100 ft-lb of torque.

A final torque of 175 ft-lb was then applied to each top nut except for aluminum safety nuts, where they were tightened until the top portion sheared off.

Finally, the shear load was applied on the top edge of the loading plate at a rate of 0.5 in. per minute until the two couplings fractured (if one coupling failed first, it was noted and then loading continued until both failed).

The average restrained shear per coupling was obtained by dividing the maximum shear load by 2. The order of failure of the two couplings and any defects evident on the coupling's fractured

5.2.3 Test 403 - Modified Type 31 Steel Lighting Standard With Aluminum Breakaway Couplings (1870-lb car/59.1 mph)

Test 403 was conducted according to procedures outlined for Test 63 of NCHRP Report 230, head-on at the quarter point of the bumper at 60 mph using an 1800-lb car with a dummy placed in the driver's seat. The objective was to determine if a modified Caltrans type 31 steel lighting standard made from a thinner gage steel (as explained in section 5.1.2.1,2, Figure 3) would meet all requirements of NCHRP Test 63. The summary of test data and photos taken before, during, and after the impact are shown in Figure 39. Accelerometer data plots are shown in Figures C9 to C12 in Appendix C.

5.2.3.1 Impact Description

The test vehicle, a 1979 Honda Civic, first impacted the base of the thin-walled steel lighting standard 5-1/2 in. to the left of the desired quarter point on the passenger's side of the bumper at 59.1 mph. This error in the location of initial impact on the front bumper was deemed too large, so the guidance system was modified for the next test.

The vehicle solidly impacted the pole and sheared off the couplings at the bases of the top stainless steel studs. Shortly after the initial impact, the base plate on the lighting standard pole hooked under the deformed front bumper and the front end of the Honda was lifted about 1 ft off the ground by the inertial mass

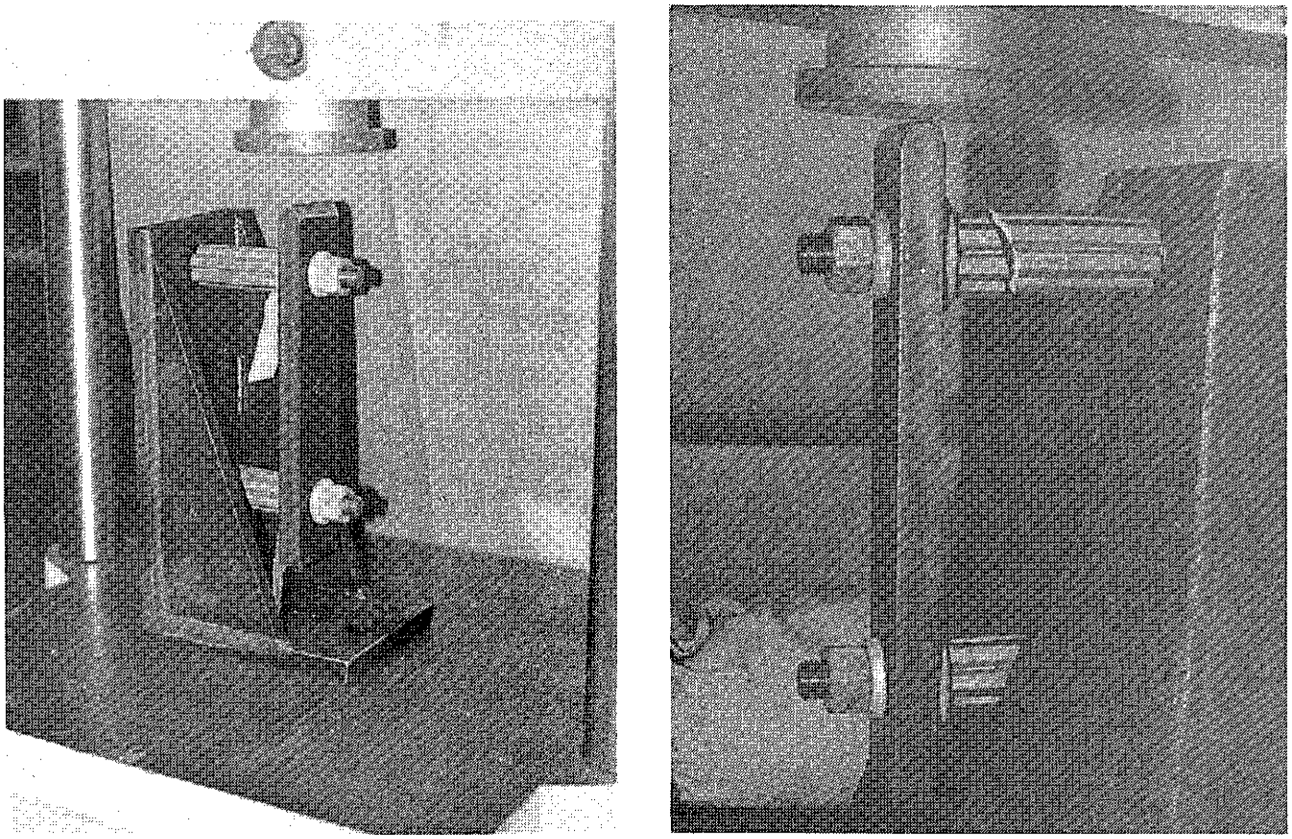


Figure 18. Restrained Shear Test Setup and Typical Failure Mode of Transpo Die-Cast Aluminum Couplings

Test Procedure

The box fixture was mounted in the testing machine capable of applying a cyclic load as shown in Figure 19.

The anchor bar stud was screwed into the base of the coupling so that it extended 2-5/8 in. into the coupling. With the top nut and hardware removed from the coupling and the unthreaded end of the anchor bar pointing upward, the specimen was positioned in the testing machine such that 3 in. of the anchor bar shank was gripped with the upper grip located in the upper crosshead of the testing machine. The top stud of the coupling was then positioned into the 1-1/8-in.-diameter hole located in the top face of the box fixture by raising the testing machine's actuator slowly. The actuator was raised until a 100 lb compressive force was applied on the coupling body.

The top washer was then replaced and the top nut was screwed onto the coupling stud. The top nut was tightened to a torque of 175 ft-lb, except for aluminum safety nuts, where they were tightened until the top portion sheared off.

Next, the load range and span was adjusted for the desired minimum/maximum loads. The cyclic load was then applied at a frequency of 10 hertz or less until failure occurred or 2 million cycles was attained.

A short-term direct tension test was conducted on specimens

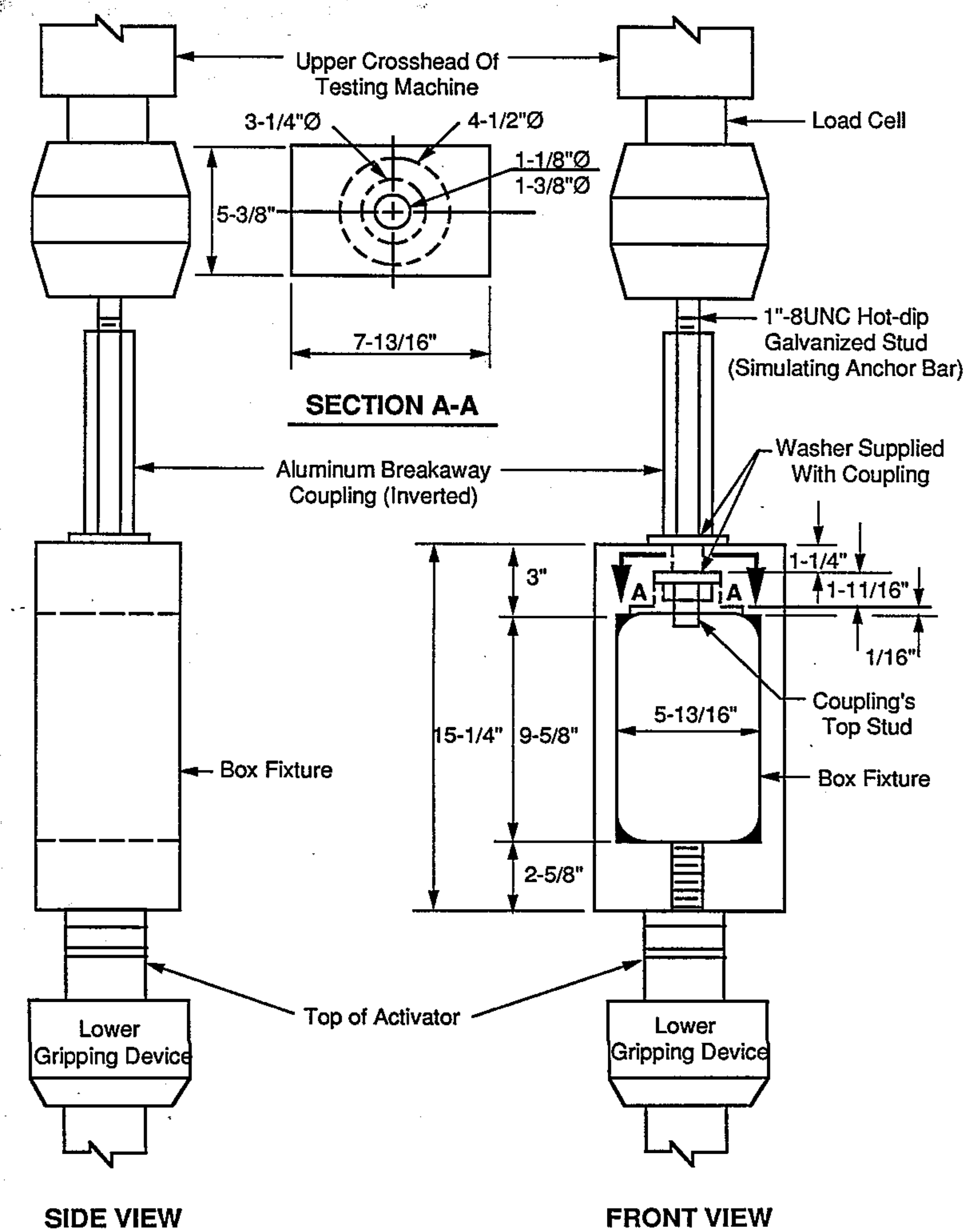


Figure 19. Test Fixture for Determining Fatigue Life of Aluminum Couplings

which had reached 2 million cycles without failing, before removing the specimen from the test fixture. Test results are given in Tables 8 and 9, section 5.2.8.2.

5- Corrosion Tests

The objectives were to study the couplings (ALCOA and Transpo) general corrosion characteristics and to determine if ALCOA aluminum nuts were acceptable for use with ALCOA couplings. Corrosion tests were performed by subjecting the aluminum couplings to a 1000-hour fog spray test according to ASTM B177.

Test Specimen

The test specimen consisted of the following:

- Three ALCOA aluminum breakaway couplings and two ALCOA aluminum nuts.
- One Transpo Industries aluminum breakaway coupling.
- Four 1 in.-8 UNC, 8-in.-long ASTM A307 hot-dip galvanized bars with 4 in. of thread on one end and two 1 in.-8 UNC hot-dip galvanized hex nuts tapped oversized.
- One 9 in. x 9 in. x 7 in. class A portland cement concrete block.
- One 8 in. x 8 in. x 1/4 in. ASTM A36 steel plate with 4 holes to accept studs of aluminum couplings.

Test Procedure

Figure 20 shows the setup for corrosion test. With the nut and washers removed, the top stud of each of the four couplings was inserted into the holes of the 8 in. x 8 in. x 1/4 in. plate. The top washers were then replaced and the 2 ALCOA aluminum nuts were

Alcoa Breakaway Couplings:

1. With Alcoa AL torque control nut
2. Duplicate of No. 1
3. With 1" - 8 UNC galvanized steel hex nut

Transpo Industries Breakaway Coupling:

4. With 1" - 8 UNC galvanized steel hex nut

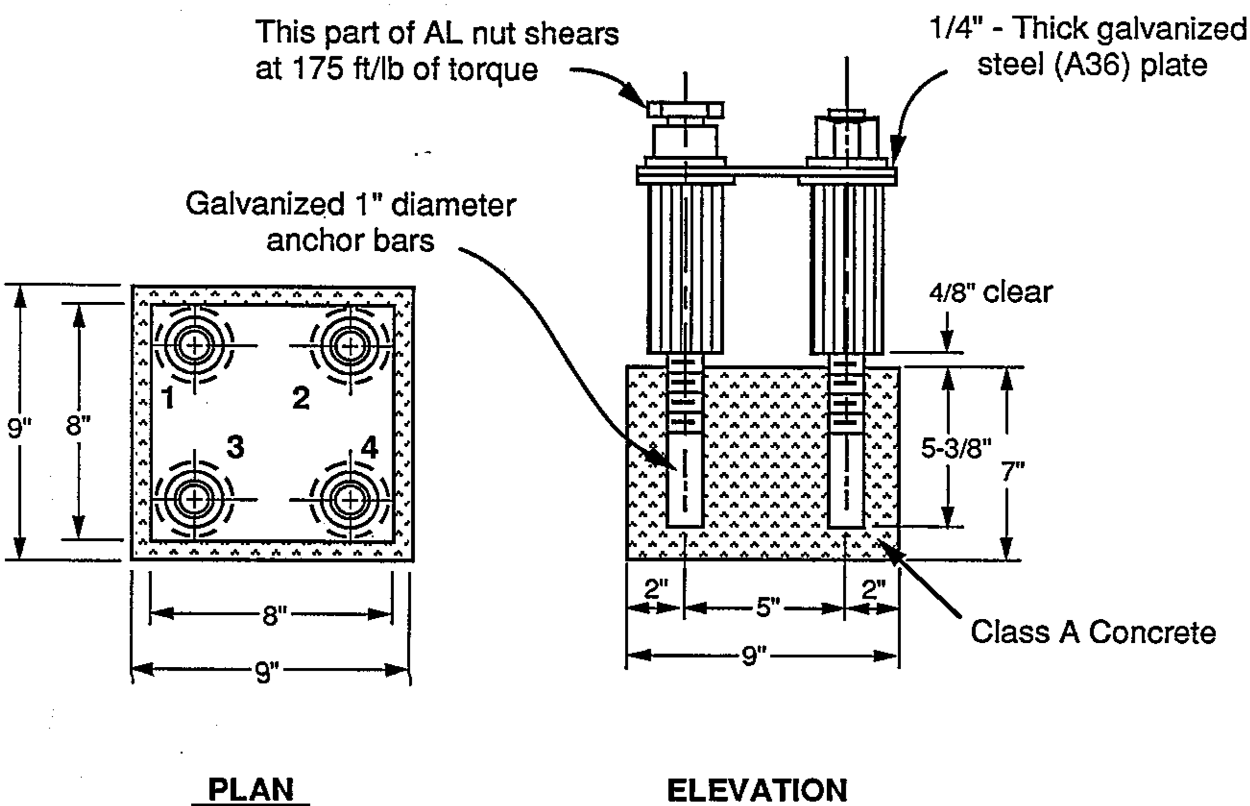


Figure 20. Corrosion Test Assembly for Evaluating Aluminum Couplings

screwed onto the top studs of the two diagonally located couplings. The two hot dip galvanized hex nuts were then screwed onto the two remaining (one ALCOA and one Transpo) coupling studs. Each nut was first snug tightened and then each was tightened to 175 ft-lb torque (standard hex nuts) or until the torque control nuts sheared off.

Next, the anchor rods were screwed into the female threads of the couplings until they entered 2-5/8 in. into the coupling body. A 9 in. x 9 in. x 7 in. concrete block with the anchor bars embedded (1/8 to 3/8 gap between the bottom of each coupling and the concrete surface) was then cast and the concrete was cured for 7 days.

The test assembly was then subjected to a salt spray fog test (ASTM B177). To prevent water from accumulating on any part of the assembly, the specimen was placed at a 30-degree angle (from vertical plane) in the test chamber, Figure 21. The test was stopped every 250 hours and the nuts, studs, and couplings were inspected for corrosion. The test assembly was removed after 1000 hours and it was inspected for excessive corrosion. Finally, the couplings and the upper nuts were sawed in half to inspect for corrosion of internal threads. Test results are given in Table 10, section 5.2.8.2.

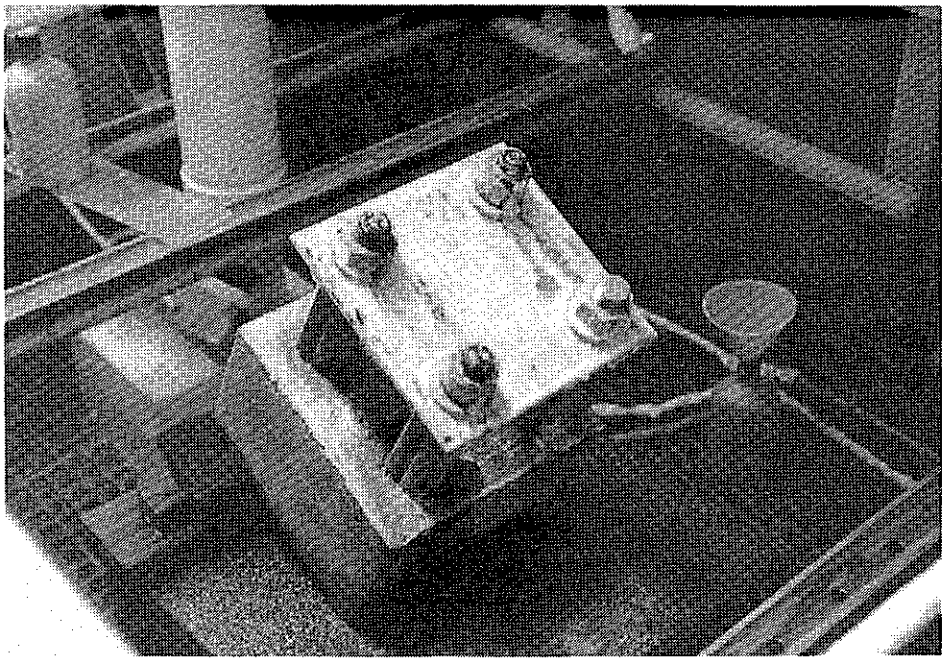


Figure 21. Corrosion Test Chamber for Evaluating Aluminum Couplings

5.2 Test Results

The detailed test data obtained from high speed photography and accelerometers are given in Appendices B and C. Discussion and evaluation of test results according to the guidelines of NCHRP Report 230 are given in section 5.3, Discussion of Test Results. A table comparing the results from crash Tests 401 to 407 and tests done by other agencies is also given in Appendix D.

5.2.1 Test 401 - Aluminum Lighting Standard With Aluminum Breakaway Couplings (1890-lb car/58.6 mph)

Test 401 was conducted according to procedures outlined for Test 63 of NCHRP Report 230, head-on at the quarter point of the bumper at 60 mph using an 1800-lb car with a dummy placed in the driver's seat. The objective of this test was to evaluate a lightweight Caltrans type 31 lighting standard made from aluminum (for details of the lighting standard see section 5.1.2.1,1, Figure 2) and equipped with aluminum breakaway couplings for meeting requirements of NCHRP Test 63. The summary of test data and photos taken before, during, and after the impact are shown in Figure 22. Accelerometer data plots are shown in Figures C1 to C4 in Appendix C.

5.2.1.1 Impact Description

A 1979 Honda Civic test vehicle impacted the base of the aluminum pole 12 in. to the right of the centerline of the front bumper (a 3-in. deviation from the desired quarter point location of 15 in. to the right of centerline) at 58.6 mph. The couplings sheared off as intended, and the vehicle pushed the pole base up and passed under the pole as it decelerated in a fairly straight line without significant yaw. The final position of the vehicle after it was braked remotely (240 ft downstream from the foundation) and the final location of the lighting standard are shown in Figure 23.

5.2.1.2 Aluminum Breakaway Couplings Performance

The couplings fractured as expected, with the bottom two thirds of the couplings remaining intact on the anchor bar studs as shown in Figure 24. Cracks in the couplings initiated in the root of the "V" notches at the top of the coupling and progressed downward until they reached a location near the base of the top stainless steel stud. The two stainless studs on the upstream side of the lighting standard, which remained in the holes in the base plate at the bottom of the aluminum pole, impacted and bent the two downstream anchor bar stubs which were directly in their path. Figure 25 shows the schematic of the vehicle approach direction and the anchor bar stubs after the impact. This vehicle approach direction offers the highest shear resistance as required by NCHRP Report 230. This condition would not normally be present because of the typically skewed approach angle of an errant vehicle. No relative movement between the concrete foundation and the surrounding asphalt concrete occurred due to the impact.

Excessive porosity was noted on the fractured surfaces of the broken couplings as shown in Figure 26.

5.2.1.3 Lighting Standard Damage and Trajectory

The surface of the aluminum pole at the impact point was not dented or deformed. The top of the pole; however, swung and impacted the asphalt pavement, destroying the end cap and bending the back of the top edge of the pole. This caused the truss type mast arm to buckle severely in two places. The pole, however, was reusable for the next crash test, Test 402.

Figure 27 shows pictorially the damage and the final location of the lighting standard. As shown, the base of the lighting standard pole came to rest 48.5 ft downstream and 8.5 ft toward the outside lane from the original location of the foundation. The mast arm rotated 180 degrees and came to rest well out of the way of traffic in the outside lane.

5.2.1.4 Luminaire Damage

The luminaire separated from the mast arm shortly after initial impact and was badly damaged after hitting the ground. Various parts of the luminaire landed outside the traffic lanes.

5.2.1.5 Vehicle Damage

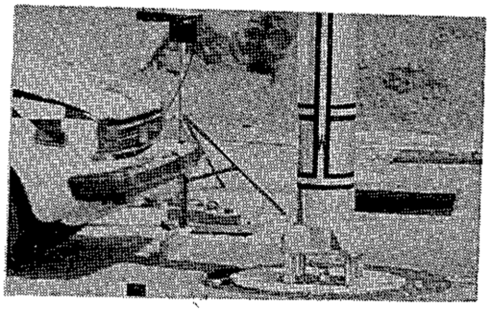
Figure 28 shows the test vehicle after the impact. The front crush profiles of the vehicle (measured in horizontal planes at different heights) are shown in Figure 29. Maximum crush of the bumper was 11.25 in. at the impact point.

The radiator was pushed back to the fan, but the engine did not move. The vehicle could not be driven away after the impact;

however, it could be rolled away. There was no intrusion of vehicle or lighting standard components into the passenger compartment.

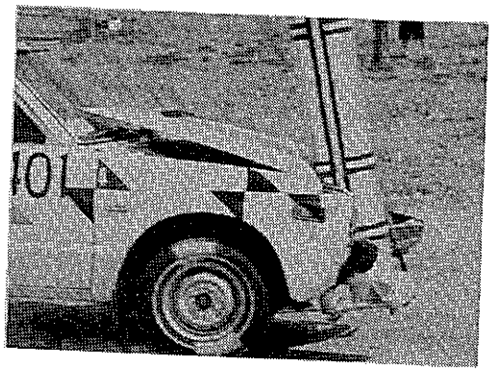
5.2.1.6 Dummy Behavior

The anthropomorphic dummy positioned in the driver's seat was unrestrained. At the initial impact, the dummy leaned forward slightly, but did not move much or hit any object inside the car. When brakes were applied, the dummy leaned forward a bit more but was still back from the steering wheel. After the impact, the dummy was found slumped slightly in the driver's seat, leaning a bit toward the passenger side of the vehicle.



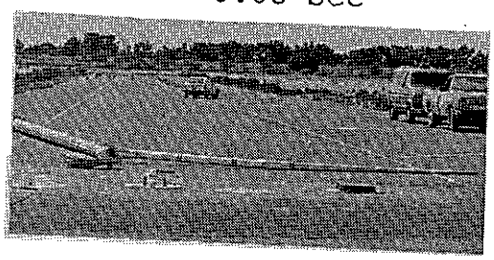
0.04 Sec Before Impact

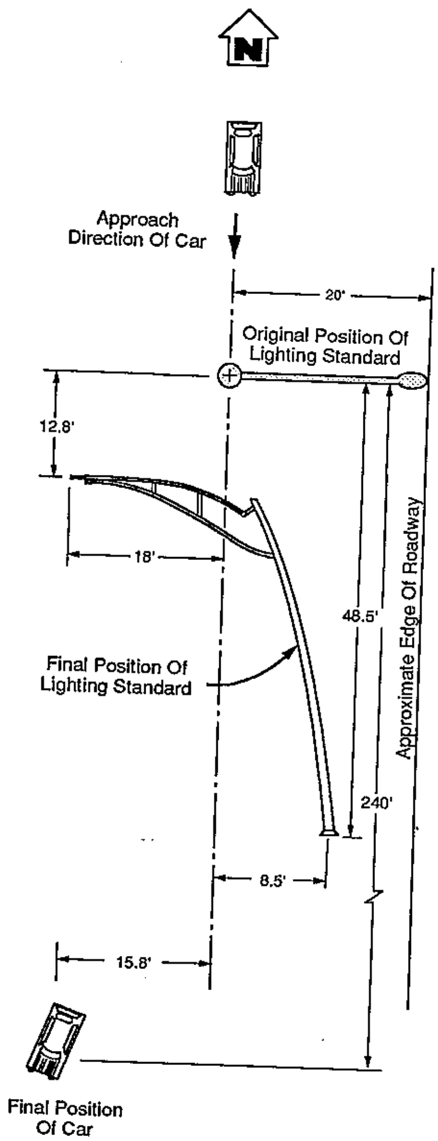
I + 0.02 Sec



I + 0.05 Sec

I + 0.08 Sec





VEHICLE	1979 Honda Civic
VEHICLE WEIGHT (Including dummy & instrumentation)	2055 Lb.
DUMMY RESTRAINT	None
IMPACT VELOCITY	58.6 Mph
IMPACT LOCATION	12" Right of centerline
OCCUPANT IMPACT VELOCITY LONG.	9.4 fps
VEHICLE DAMAGE (measured at bumper ht.)	11-1/4"
VEHICLE ACCELERATION (max. 50 msec avg.)	
LATERAL	-0.80 g's
LONGITUDINAL	-3.80 g's
VERTICAL	-0.85 g's
HEAD INJURY CRITERION	1.8

TEST NO.	401
DATE	August 25, 1982
TYPE OF LIGHT STD.	Modified Type 31
POLE MATERIAL	Aluminum
POLE DIMENSIONS	35'-0" x 10"O.D. x 8"O.D.
POLE BASE SLEEVE	0.257" x 2'-0" High
MOUNTING HEIGHT	37'-0"
PROJECTED LENGTH OF MAST ARM	20'-0"
TOTAL WEIGHT	394 Lb.
BREAKAWAY DEVICE	Aluminum Couplings

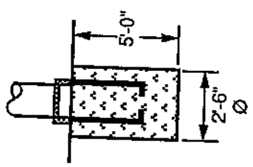


Figure 22. Test 401 Data Summary Sheet

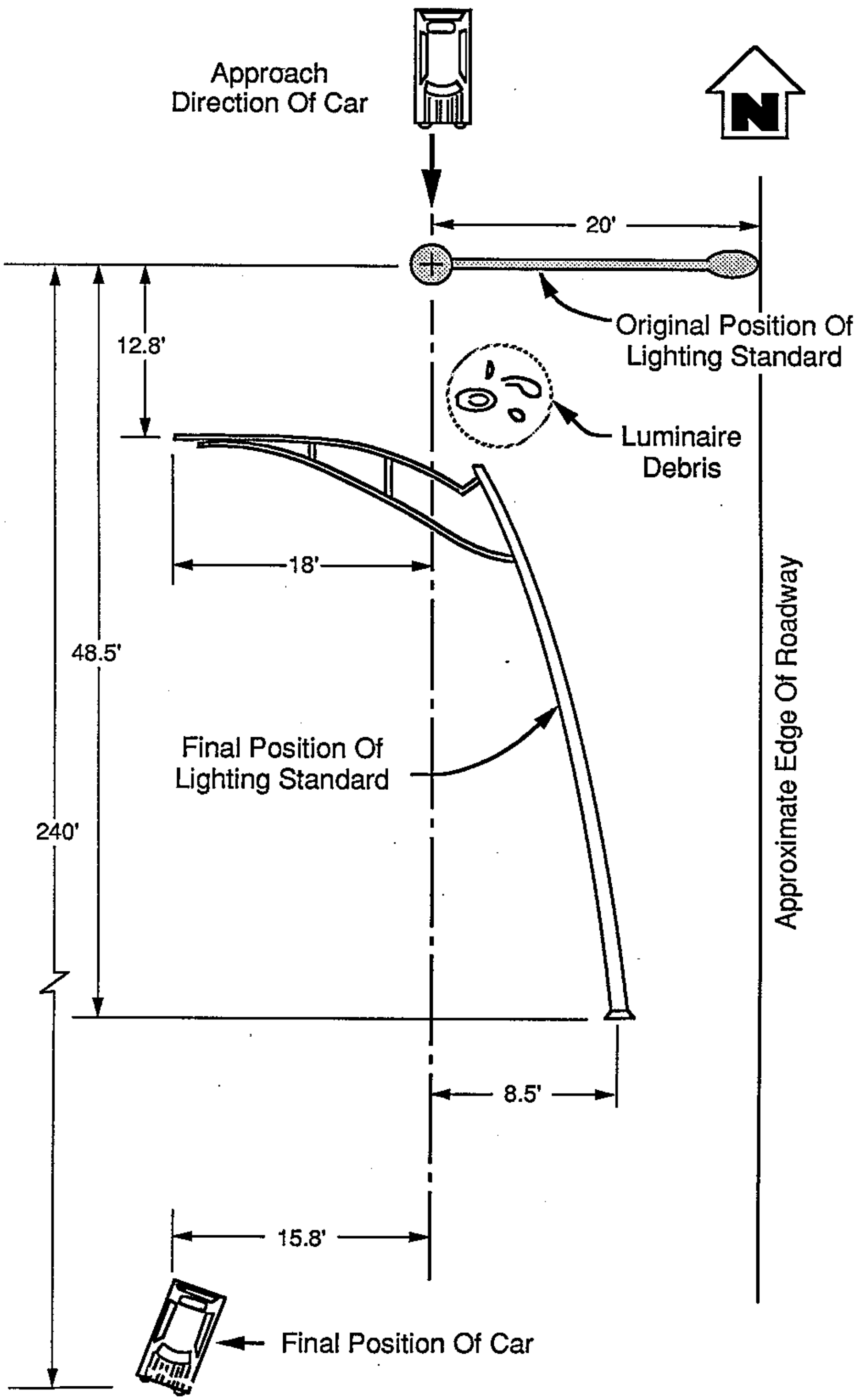


Figure 23. Final Location of the Lighting Standard and the Car After Collision - Test 401

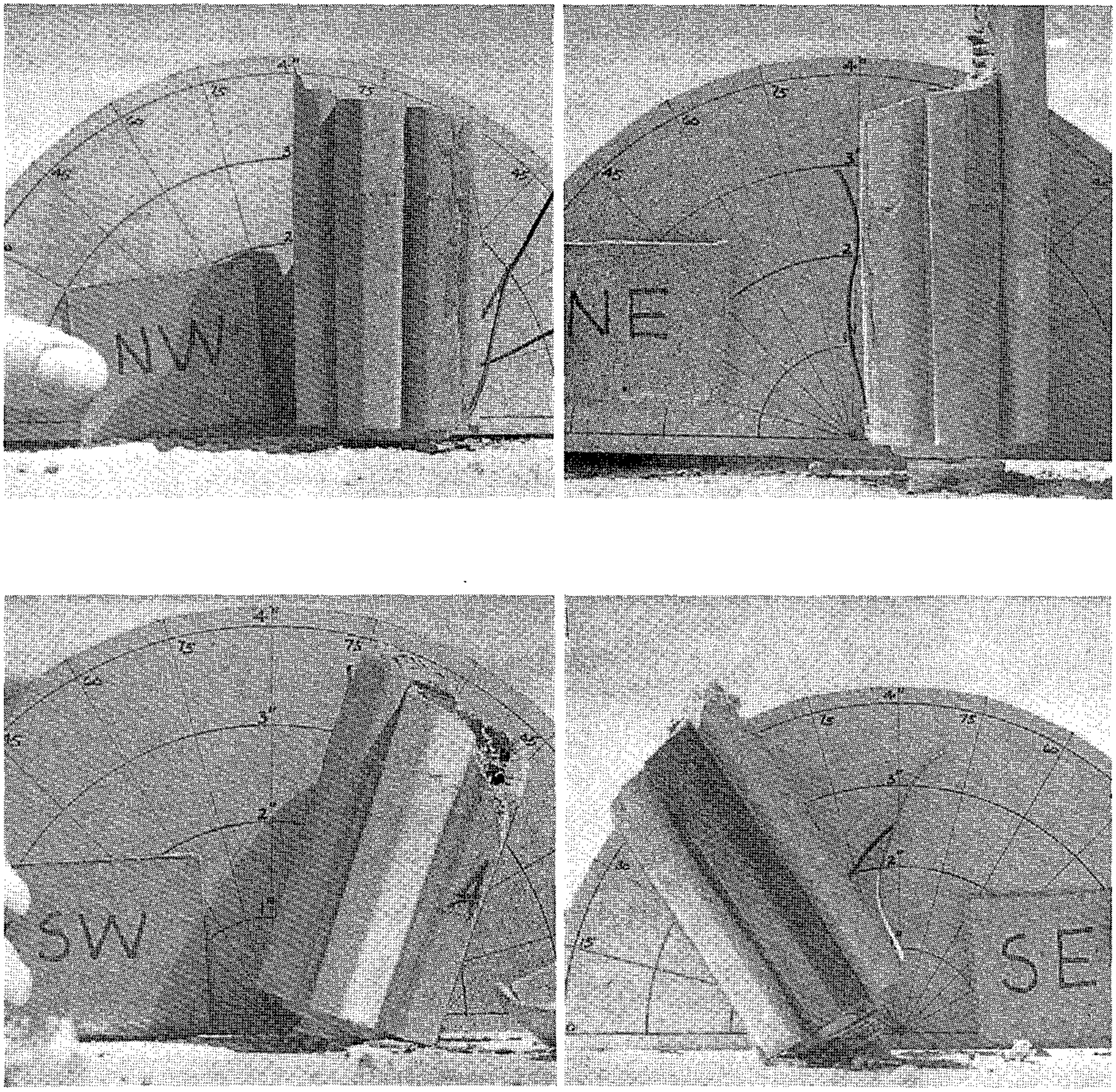
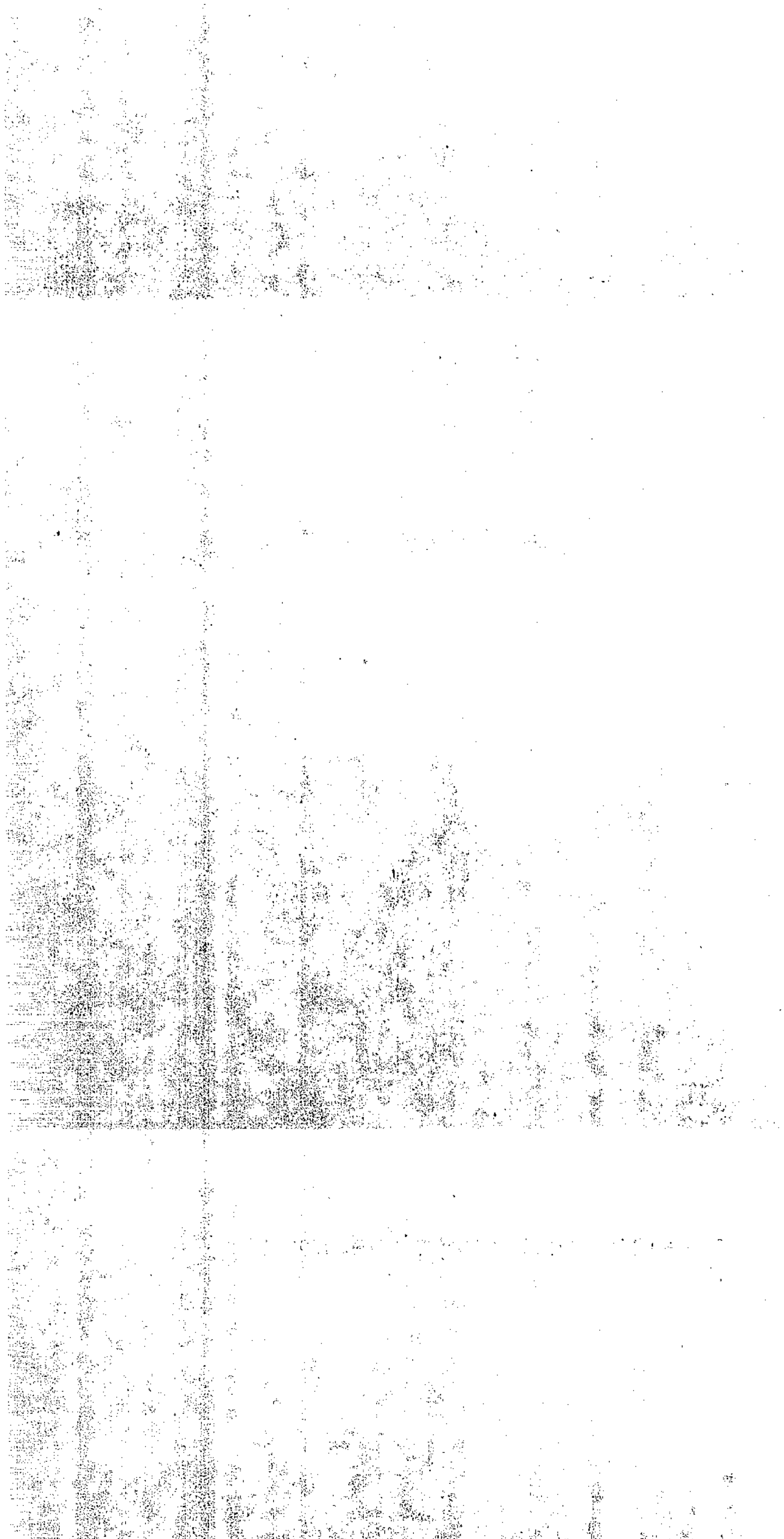


Figure 24. Die-Cast Aluminum Couplings After Impact - Test 401



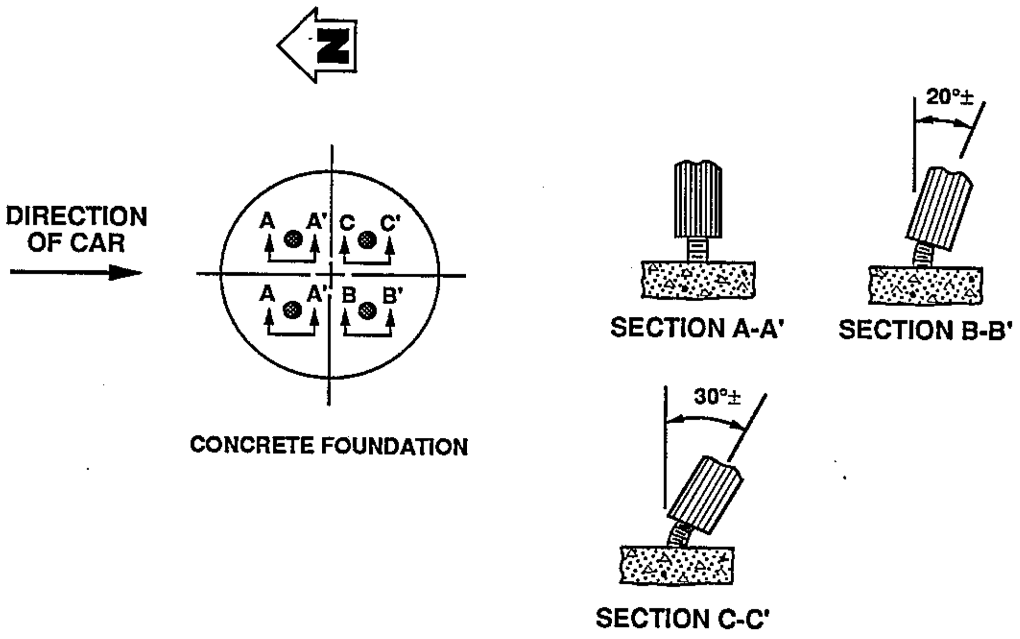
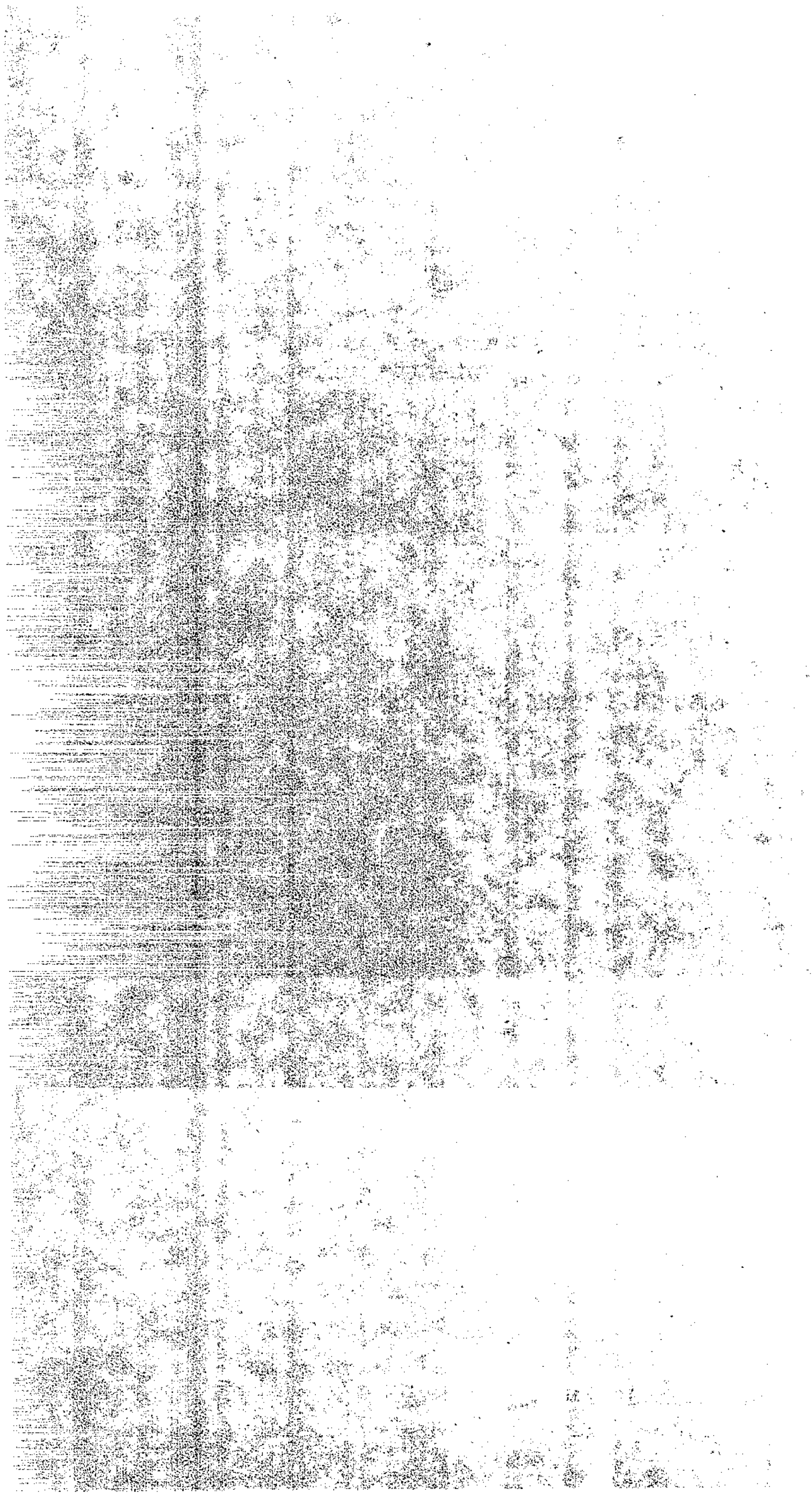


Figure 25. Anchor Bolt Stub Details After Impact - Test 401



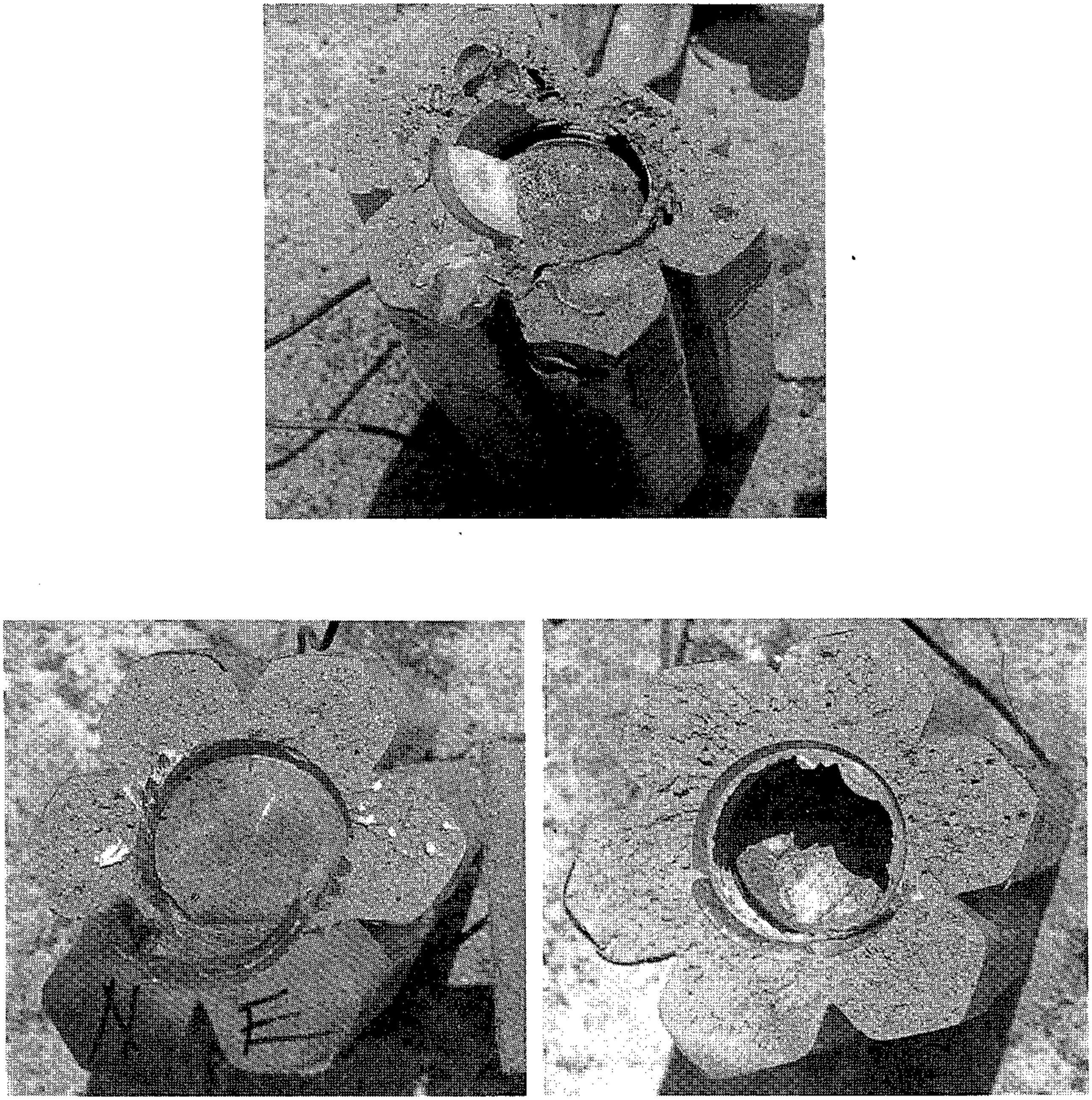
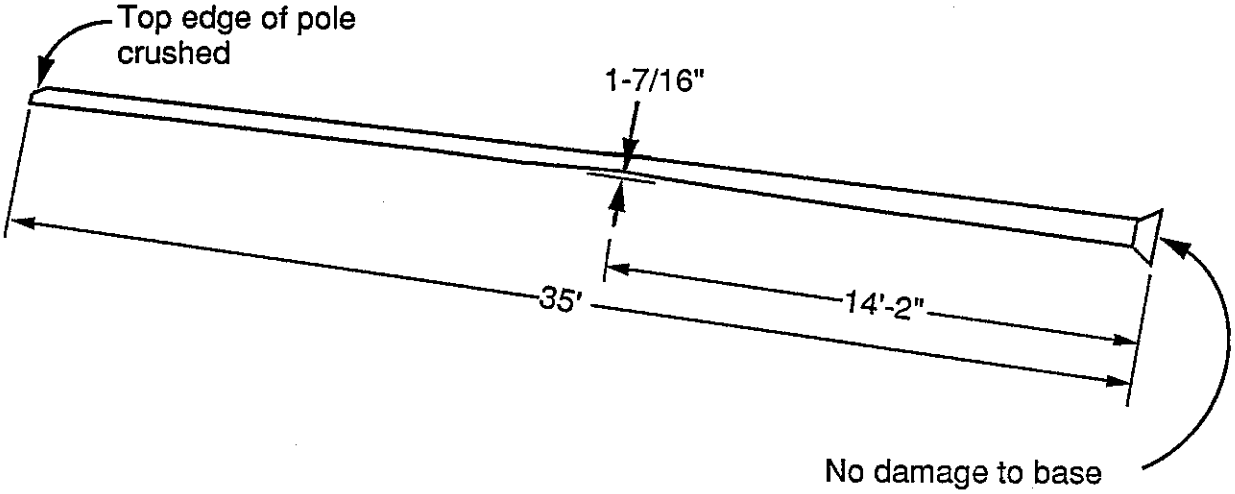


Figure 26. Fractured Surfaces of Die-Cast Aluminum Couplings - Test 401



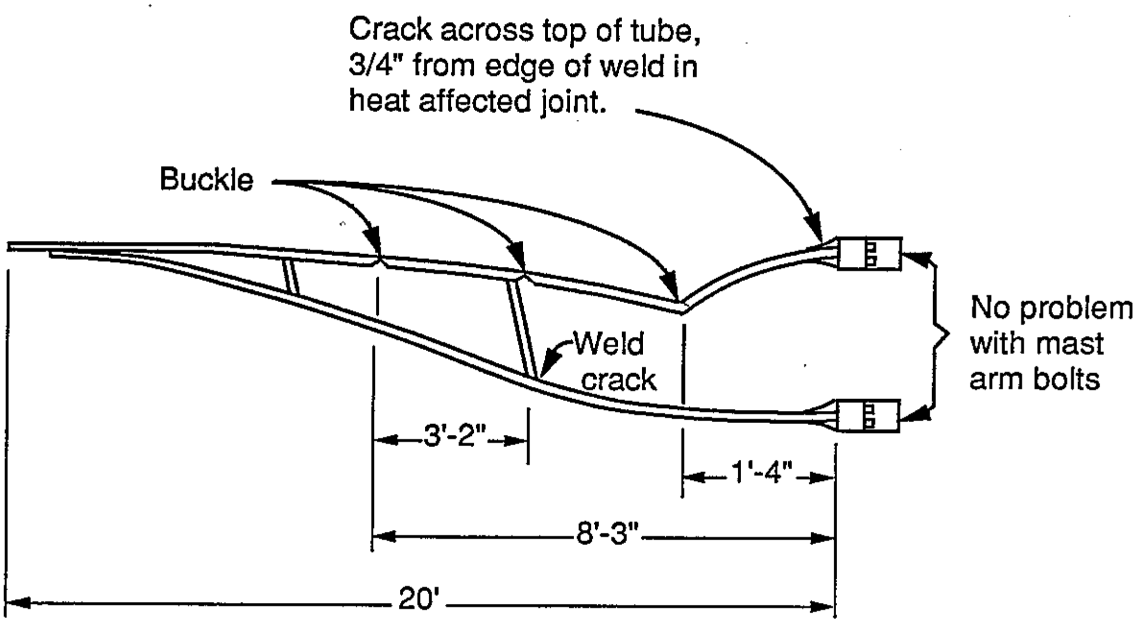


Figure 27. Damage To The Pole And The Mast Arm - Test 401

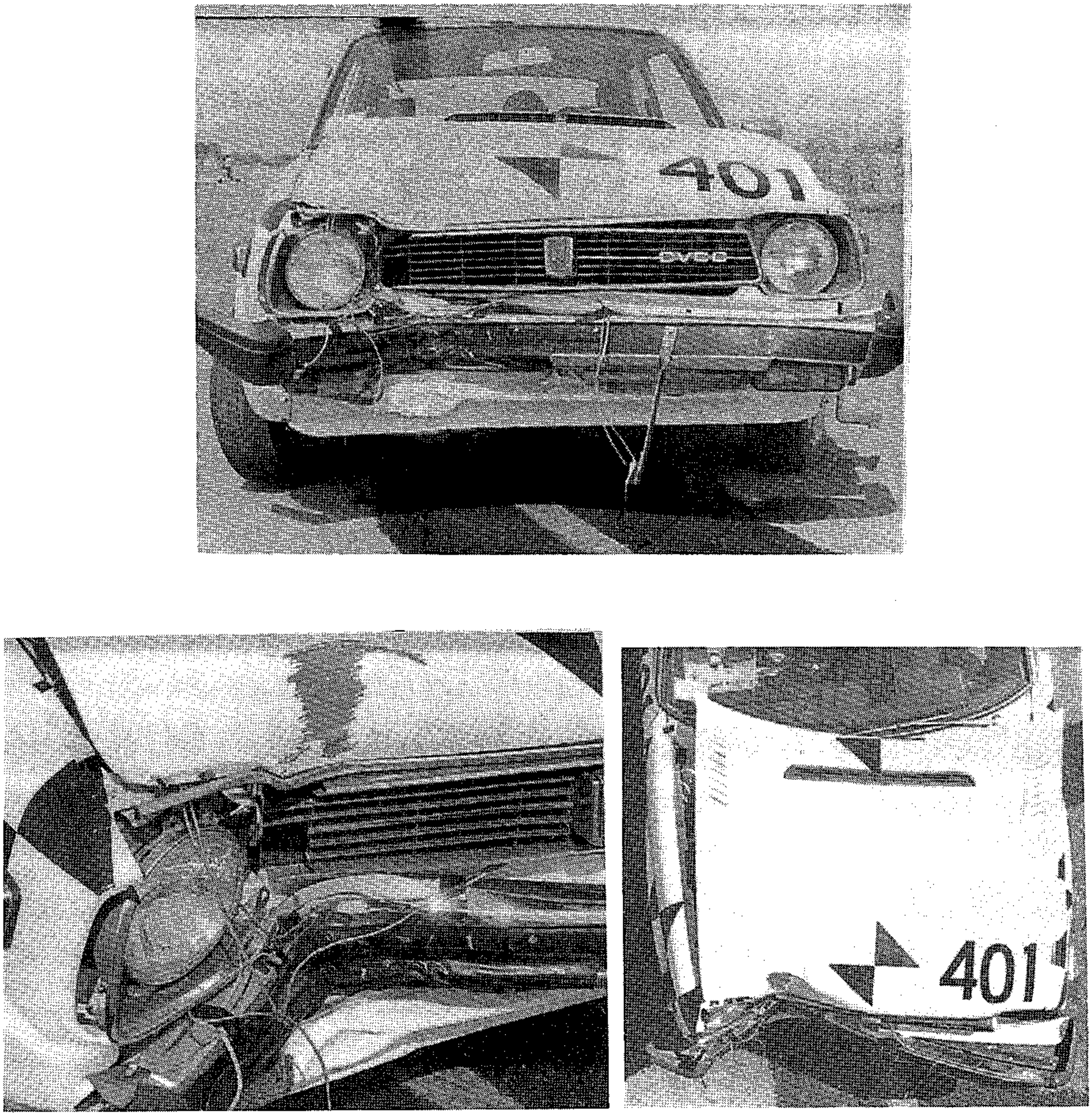


Figure 28. Test Vehicle After Impact - Test 401

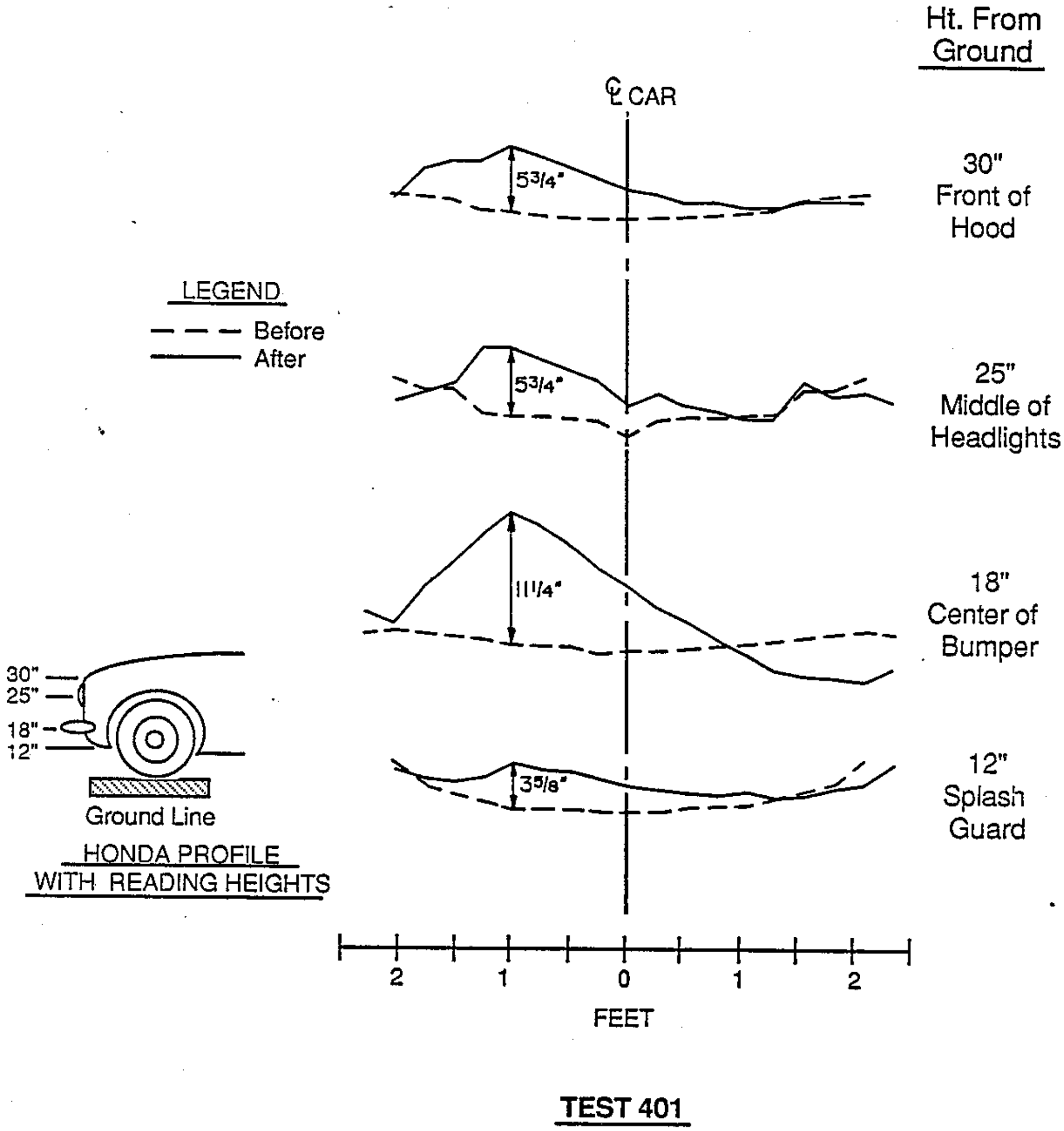


Figure 29. Crush Profiles of the Front End of Test Vehicle - Test 401

5.2.2 Test 402 - Aluminum Lighting Standard With Aluminum Breakaway Couplings (1850-lb car/19.6 mph)

Test 402 was conducted according to procedures outlined for Test 62 of NCHRP Report 230, head-on at the center of the bumper at 20 mph using an 1800-lb car with a dummy placed in the driver's seat. The objective of this test was to evaluate a lightweight Caltrans type 31 lighting standard made from aluminum (for details of the lighting standard see section 5.1.2.1,1, Figure 2) and equipped with aluminum breakaway couplings for meeting requirements of NCHRP Test 62. The summary of test data and photos taken before, during, and after the impact are shown in Figure 30. Accelerometer data plots are shown in Figures C5 to C8 in Appendix C.

5.2.2.1 Impact Description

The 1979 Honda Civic test vehicle impacted the aluminum pole at the center of the front bumper at 19.6 mph. Upon impact, the couplings sheared off and the vehicle pushed and bumped the pole along in front of the decelerating auto. The pole was pushed over slowly and it rolled on the roof as the car barely passed under the pole base plate. The vehicle traveled in an almost straight line after impact, drifting slightly to the left with virtually no yaw. The final position of the vehicle after the brake had been applied was 56.5 ft from the foundation as shown in Figure 31.

5.2.2.2 Aluminum Breakaway Couplings Performance

The couplings fractured as expected. The bottom portion of the two top stainless studs which remained in the upstream side of the lighting standard shoe base, Figure 32, impacted the broken aluminum coupling stubs (still intact on the anchor bar stubs) and bent the two downstream anchor bars as occurred in Test 401. Figure 33 shows the couplings and the anchor bars after the impact. The schematic of the vehicle approach direction and the anchor bar stubs after the impact are shown in Figure 34. As mentioned before, this vehicle approach direction offers the highest shear resistance as required by NCHRP Report 230; however, the approach of an errant car is typically skewed. No relative movement between the concrete foundation and the surrounding asphalt concrete occurred due to the impact.

Figure 35 shows the excessive amount of porosity observed on the fractured surfaces of the broken couplings. This is similar to what had been observed in Test 401. As explained before (section 5.1.2.2,1), because of this excessive amount of porosity, the remaining couplings were x rayed and only those with an acceptable amount of porosity were used in the next test, Test 403.

5.2.2.3 Lighting Standard Damage and Trajectory

As in Test 401, the aluminum pole sustained no damage from the impact of the vehicle's front bumper. The top of the pole; however, swung down and impacted the asphalt pavement, damaging the end cap and top edge of the pole and causing the upper cast aluminum mast arm clamping band to fracture, Figure 36. The mast arm, however, did not buckle as it did in Test 401.

Figure 31 illustrates the final location of the lighting standard. The base of the lighting standard pole came to rest 33.7 ft downstream and 4.2 ft toward the outside lane of traffic from the original location of the foundation, with the pole laying parallel to the approach angle of the vehicle. The direction which the mast arm pointed was 180 degrees from that which occurred in Test 401. The mast arm, still attached to the pole, came to rest even with the foundation and was pointed eastward. Its tip was 25.9 ft from the foundation, projecting 5.9 ft into an imaginary outside lane of traffic.

5.2.2.4 Luminaire Damage

The luminaire broke into many pieces that were scattered over a large area (well into the imaginary traffic lanes). The largest pieces were lying about 39 ft east of the concrete foundation (Figure 31).

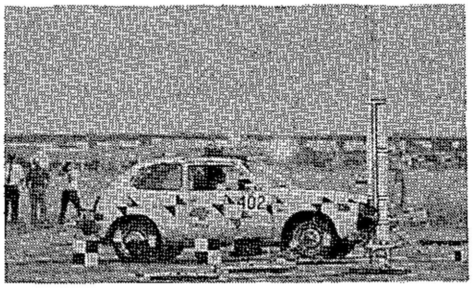
5.2.2.5 Vehicle Damage

Figure 37 shows the test vehicle after the impact. The front crush profiles of the vehicle measured horizontally at different heights are shown in Figure 38. A maximum crush of 11.25 in. was measured at the center of the bumper. The top front edge of the car's roof was dented 1.25 in. and the windshield was cracked as the pole contacted the roof of ~~the~~ auto about 8 ft up from the base plate after the impact. The rear quarter panel on the driver's side of the vehicle also had a small dent caused by the base plate barely clipping the rear quarter panel of the vehicle.

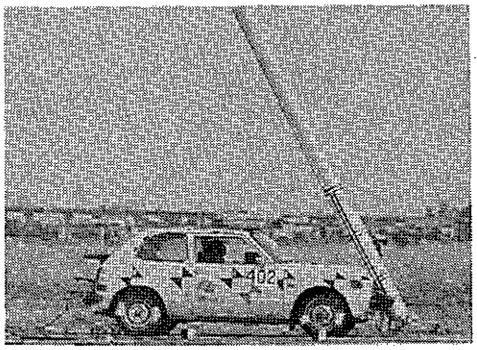
The radiator was pushed back to the fan, but the engine did not move. The vehicle could not be driven away after the impact; however, it could be rolled away. There was no intrusion of vehicle or lighting standard components into the passenger compartment.

5.2.2.6 Dummy Behavior

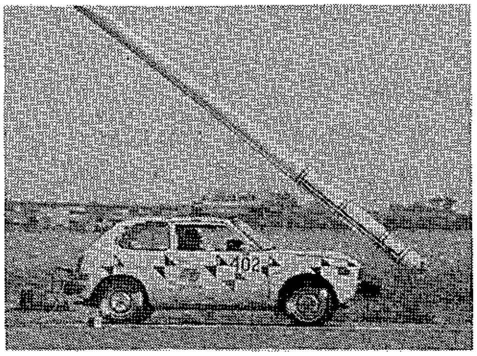
The anthropomorphic dummy, positioned in the driver's seat, was unrestrained. At the initial impact, the dummy leaned forward slightly; however, it did not move much or hit any object inside the car. When the brakes were applied, the dummy pivoted at the waist and its chest and head gently contacted the steering wheel. After the car came to rest, the dummy was found slumped back in the driver's seat, with its head and shoulders leaning slightly toward the passenger side of the vehicle.



Impact+0.02 Sec



I + 0.5 Sec



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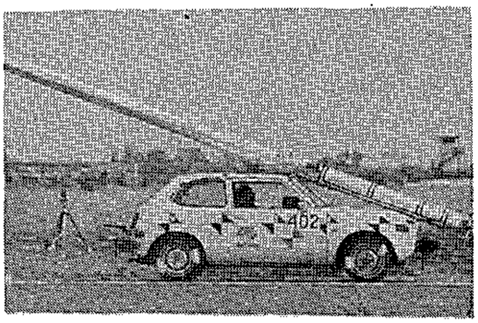
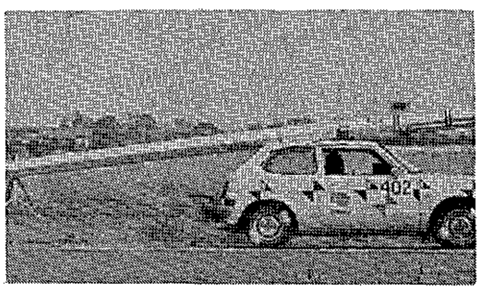


I + 1.16 Sec



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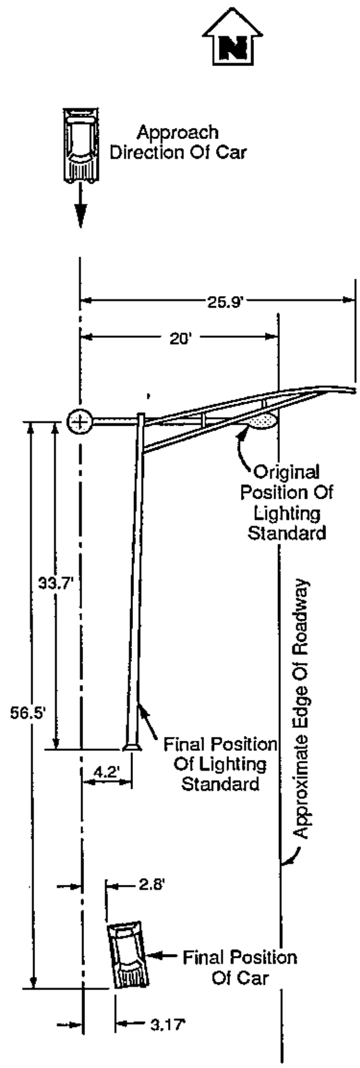


VEHICLE	1979 Honda Civic
VEHICLE WEIGHT (Including dummy & instrumentation)	2015 lb.
DUMMY RESTRAINT	None
IMPACT VELOCITY	19.6 Mph.
IMPACT LOCATION	Center of the Front Bumper
OCCUPANT IMPACT VELOCITY..LONG.	10.4 fps
VEHICLE DAMAGE (measured at bumper ht.)	11-1/4"
VEHICLE ACCELERATION (max. 50 msec avg.)	
LATERAL	-0.22 g's
LONGITUDINAL	-3.19 g's
VERTICAL	-0.74 g's
HEAD INJURY CRITERION	0.8

TEST NO.	402
DATE	October 13, 1982
TYPE OF LIGHT STD.	Modified Type 31
POLE MATERIAL	Aluminum
POLE DIMENSIONS	35' x 10"O.D x 8"O.D.
POLE BASE SLEEVE	0.257" x 2'-0" high
MOUNTING HEIGHT	37'-0"
PROJECTED LENGTH OF MAST ARM	20'-0"
TOTAL WEIGHT	394 Lb.
BREAKAWAY DEVICE	Aluminum Couplings

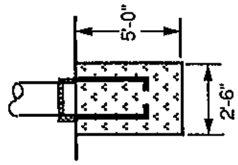


Figure 30. Test 402 Data Summary Sheet

[illegible]

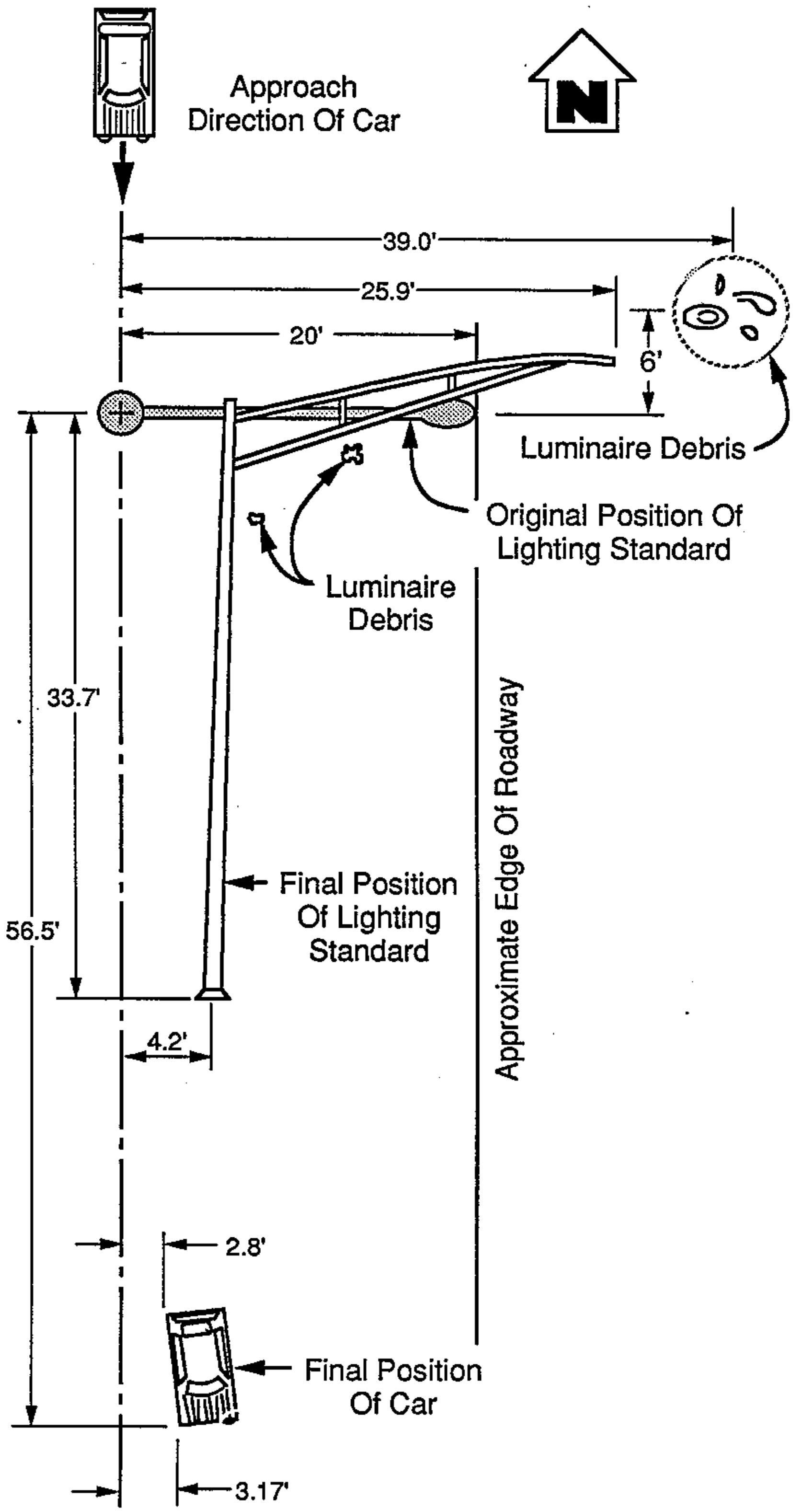


Figure 31. Final Location of the Lighting Standard and the Car After Collision - Test 402

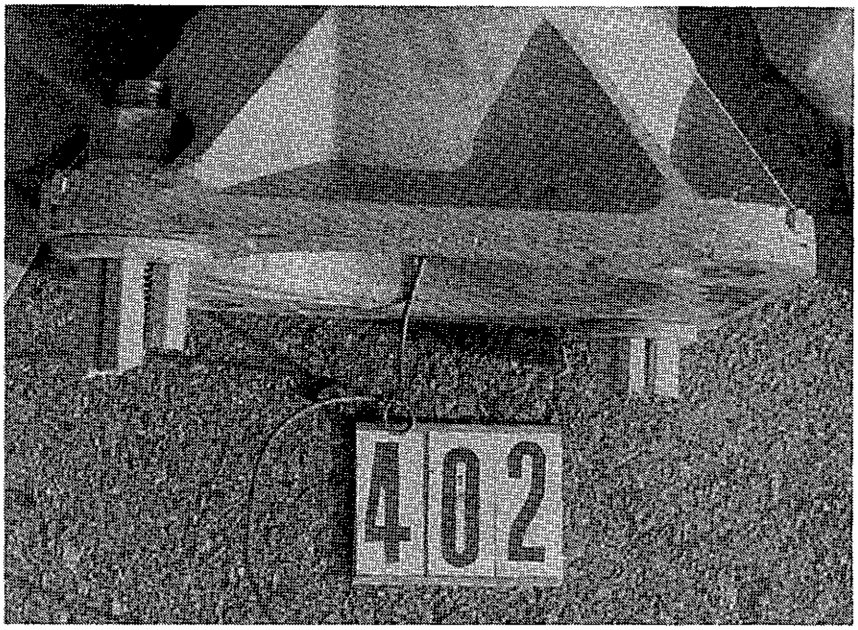


Figure 32. Aluminum Lighting Standard Shoe Base
After Impact - Test 402

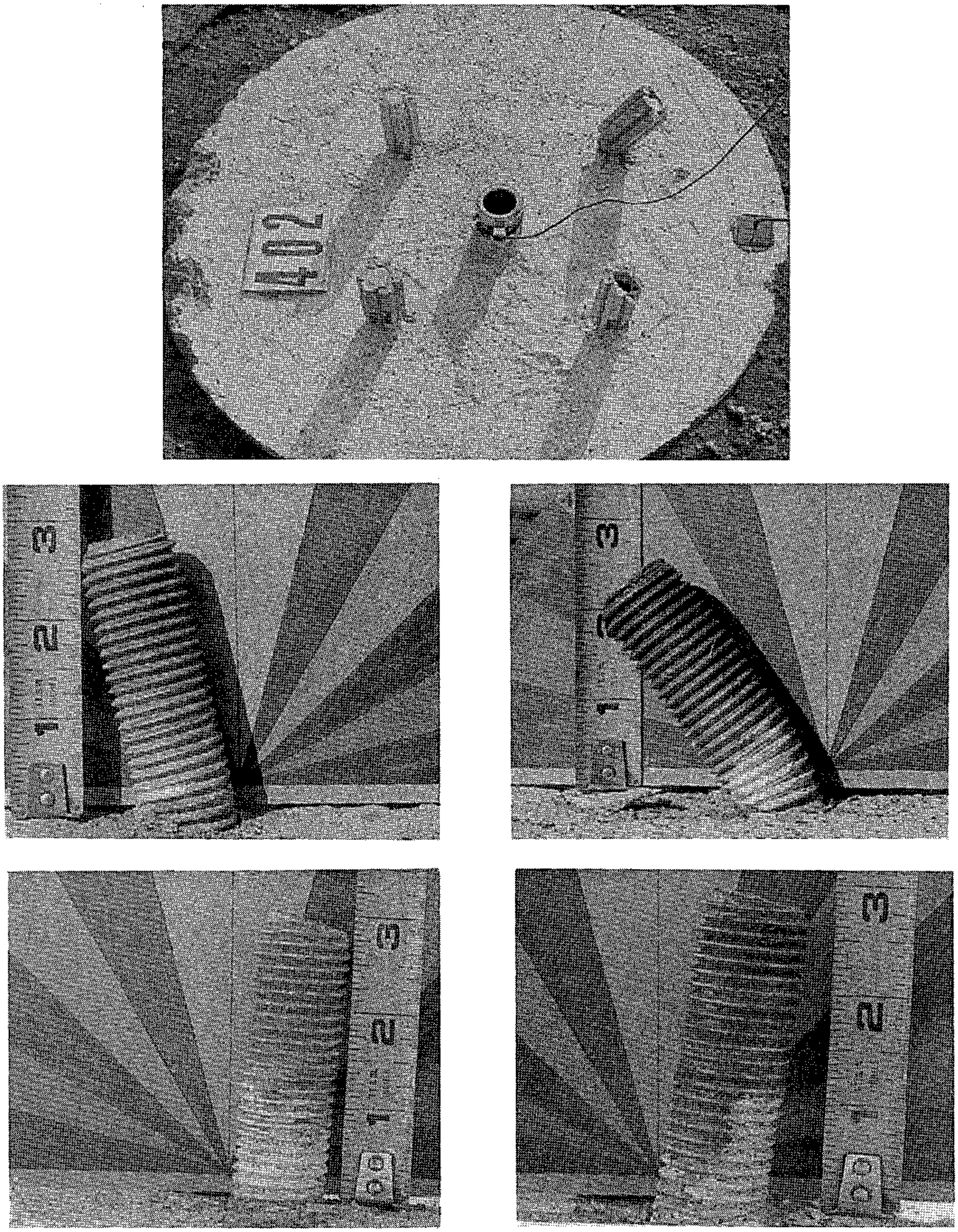


Figure 33. Die-Cast Aluminum Couplings and the Anchor Bolts After Impact - Test 402

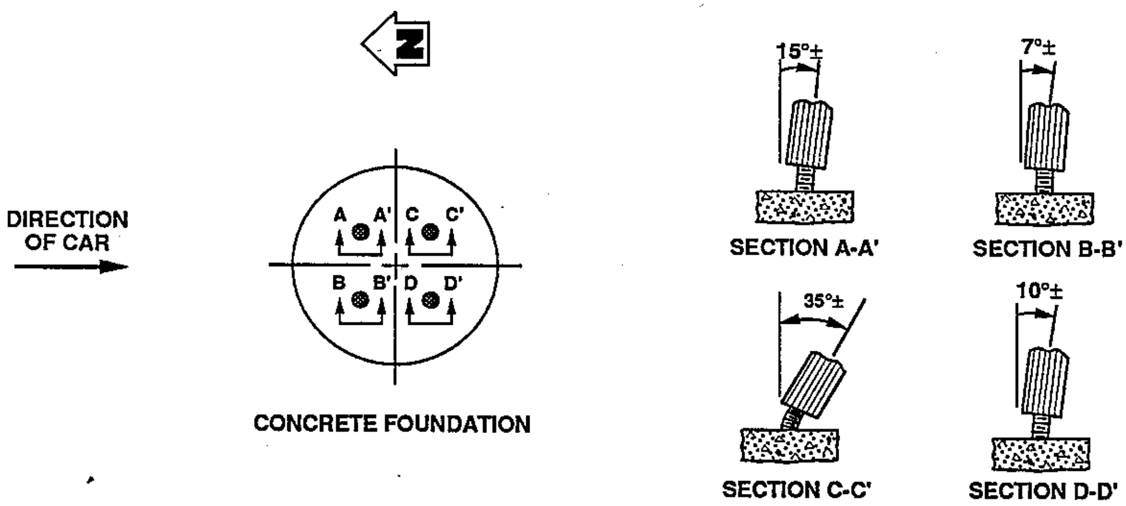


Figure 34. Anchor Bolt Stub Details After Impact - Test 402

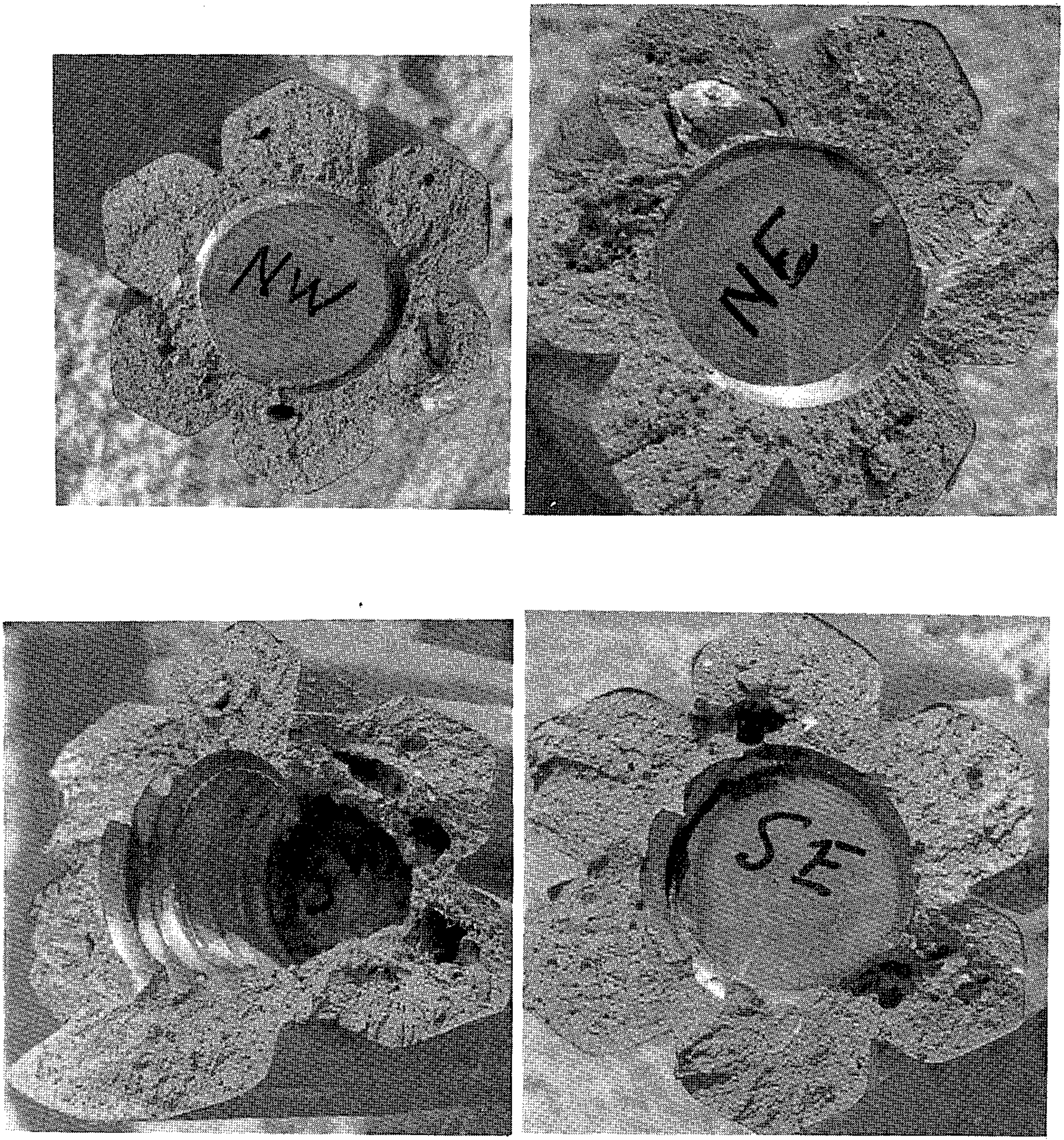
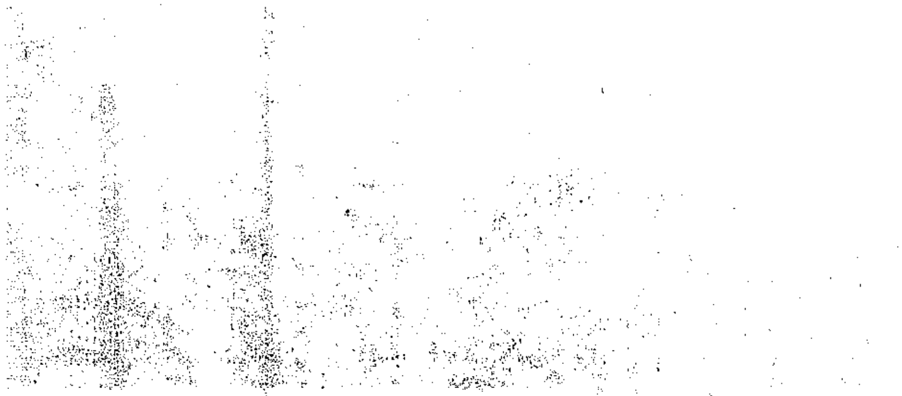
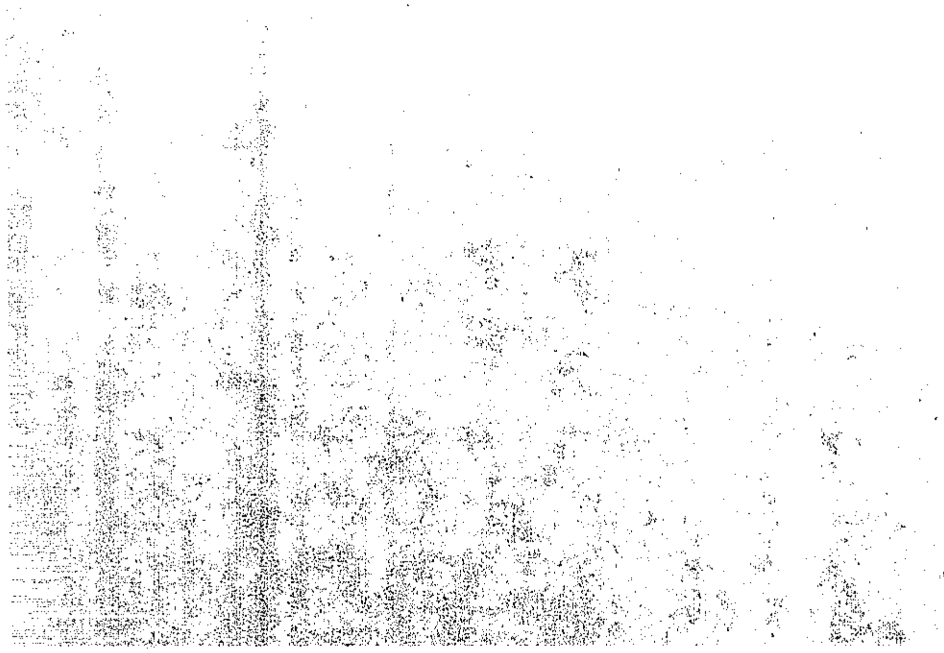


Figure 35. Fractured Surfaces of Die-Cast Aluminum Couplings - Test 402





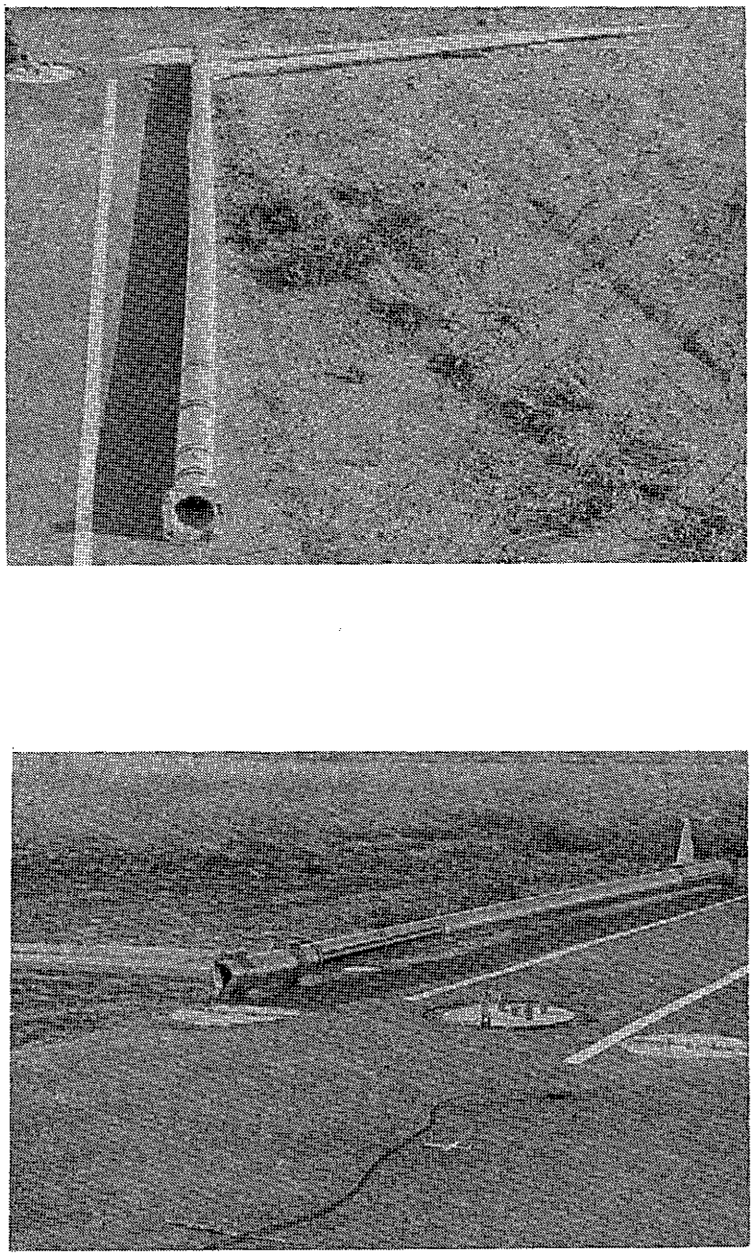


Figure 36. Lighting Standard Damage - Test 402

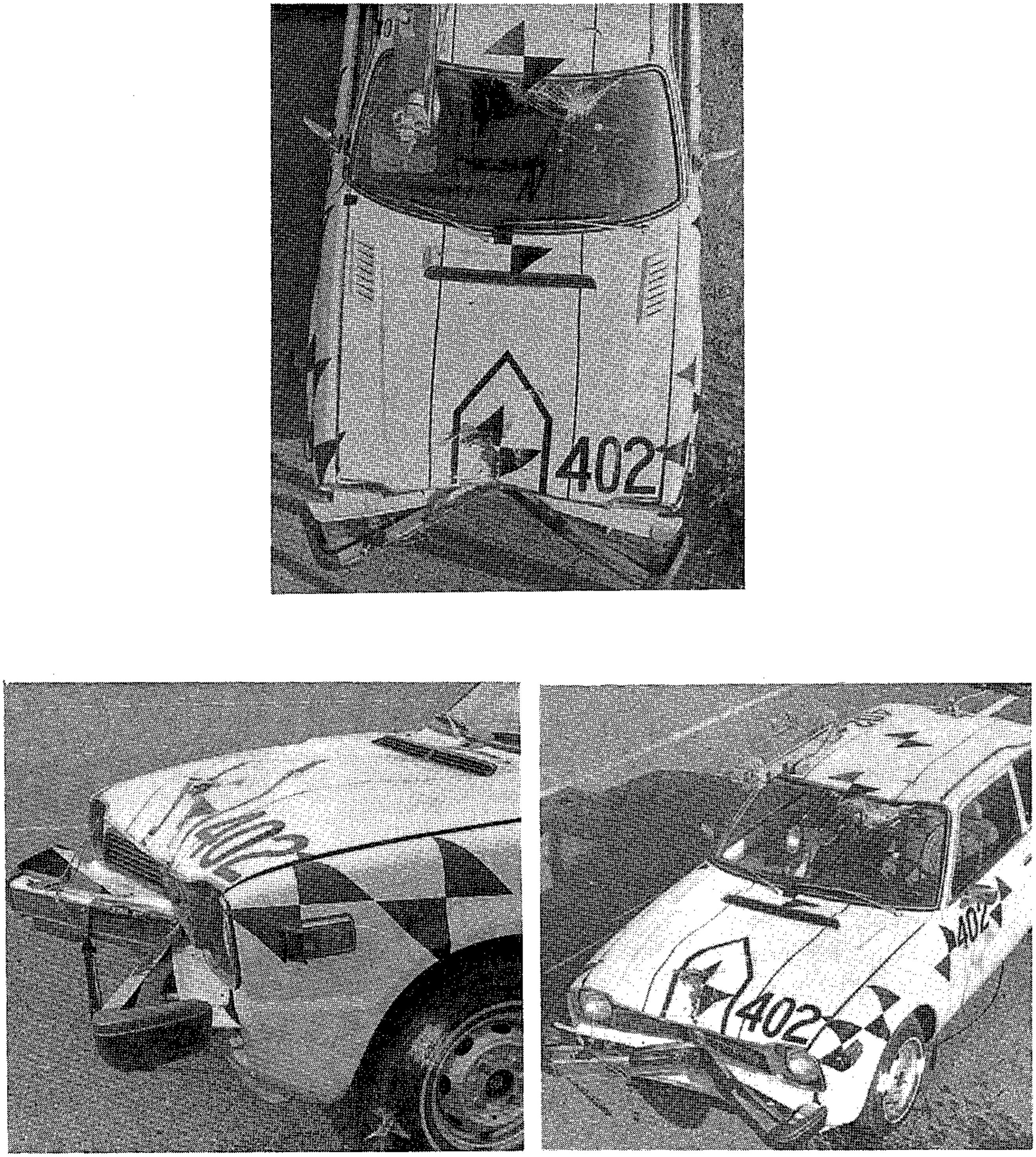


Figure 37. Test Vehicle After Impact - Test 402

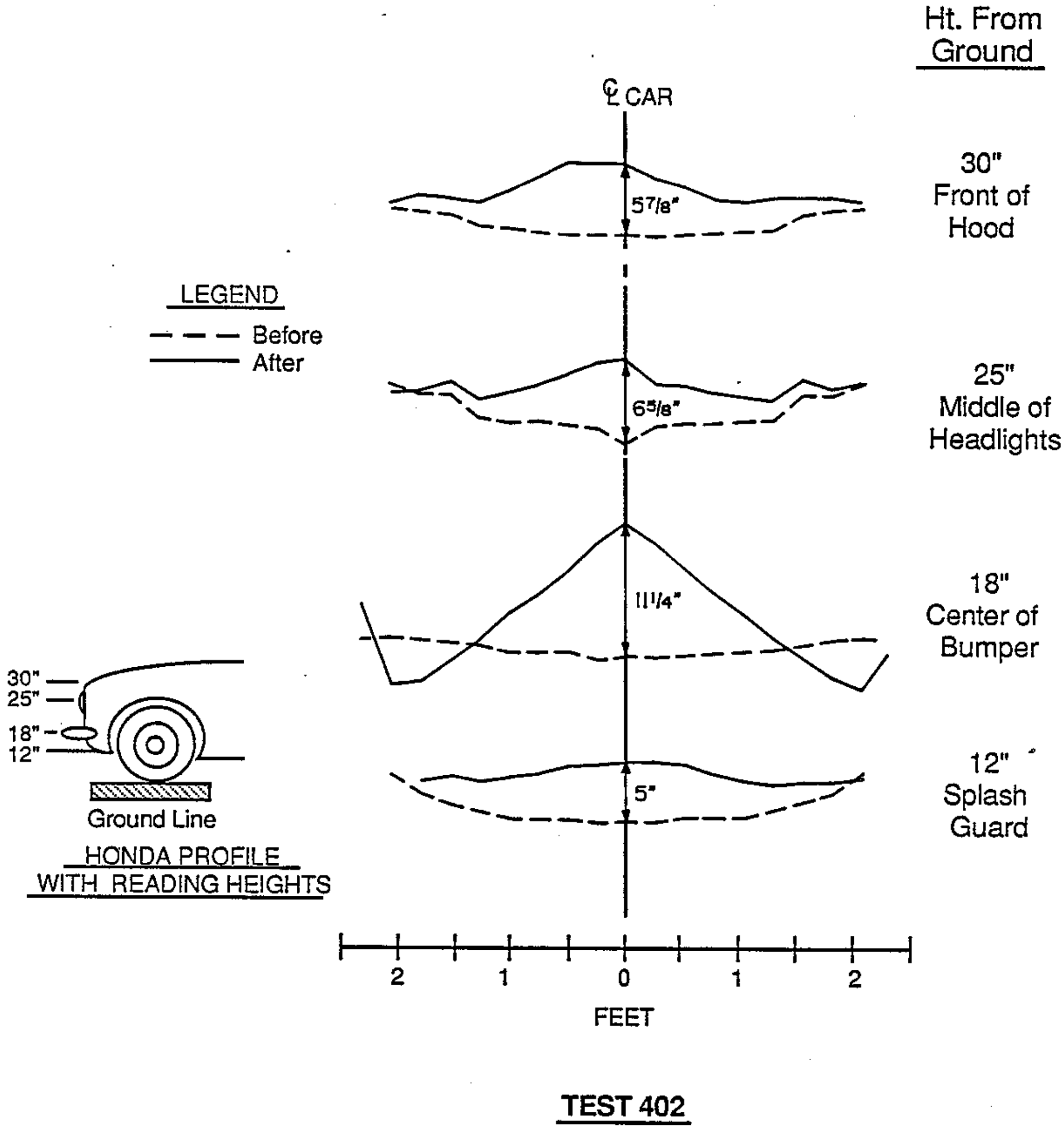


Figure 38. Crush Profiles of the Front End of Test Vehicle - Test 402

5.2.3 Test 403 - Modified Type 31 Steel Lighting Standard With Aluminum Breakaway Couplings (1870-lb car/59.1 mph)

Test 403 was conducted according to procedures outlined for Test 63 of NCHRP Report 230, head-on at the quarter point of the bumper at 60 mph using an 1800-lb car with a dummy placed in the driver's seat. The objective was to determine if a modified Caltrans type 31 steel lighting standard made from a thinner gage steel (as explained in section 5.1.2.1,2, Figure 3) would meet all requirements of NCHRP Test 63. The summary of test data and photos taken before, during, and after the impact are shown in Figure 39. Accelerometer data plots are shown in Figures C9 to C12 in Appendix C.

5.2.3.1 Impact Description

The test vehicle, a 1979 Honda Civic, first impacted the base of the thin-walled steel lighting standard 5-1/2 in. to the left of the desired quarter point on the passenger's side of the bumper at 59.1 mph. This error in the location of initial impact on the front bumper was deemed too large, so the guidance system was modified for the next test.

The vehicle solidly impacted the pole and sheared off the couplings at the bases of the top stainless steel studs. Shortly after the initial impact, the base plate on the lighting standard pole hooked under the deformed front bumper and the front end of the Honda was lifted about 1 ft off the ground by the inertial mass of the standard. As the car continued to travel downstream the base plate on the bottom of the pole unhooked from the front bumper. The pole continued moving upward well over the car roof, while the car proceeded to travel in a nearly straight line beneath the pole. Brakes were applied after it had become obvious that no significant yaw or roll would occur. The final position of the vehicle (214 ft downstream from the foundation), and the lighting standard are shown in Figure 40.

5.2.3.2 Aluminum Breakaway Couplings Performance

As mentioned in section 5.1.2.2, 1, the aluminum couplings used in this test were chosen after they had been x rayed. Those selected had level 2 porosity defects according to the ASTM E505 reference radiographs.

Upon impact, all four couplings sheared relatively cleanly just at the bases of the top stainless steel studs as shown in Figure 41. The remaining bottom portions of the two upstream couplings (marked NW and NE on Figure 41), still screwed onto the anchor bars, were approximately equal in height and projected 3-3/4 in. above the foundation surface. The stub marked NE had a sharp jagged spike on the upstream side. The two downstream stubs each had one flute intact on the upstream side which projected above the stud shear plane with the reminder of the top portion of the coupling sheared at the base of the stainless steel stud pocket. A couple of small porosity voids were noted; however, the cast aluminum material in these handpicked couplings was, on the whole, sound and nearly solid, and of much better quality than that of those used in previous tests. Most of the pieces of broken couplings were scattered far from the pole base or foundation and could not be found. The ones which were located showed good solid metal on all fractured surfaces; however, in the threaded surfaces there were streaks or lines of voids showing through the threads. This was possibly due to the lack of flow of metal around the threads of the stainless steel stud.

As in the Tests 401 and 402, the two downstream 1-in.-diameter A307 anchor bar studs which projected above the surface of the concrete foundation approximately 2-5/8 in. were bent substantially. This bending occurred as the lower portion of the stainless steel studs from the two upstream couplings (still secure in and projecting through the base plate of the pole) impacted the top edges of the two lower stubs of the downstream aluminum couplings. No relative movement between the concrete foundation and the surrounding soil backfill was evident.

5.2.3.3 Lighting Standard Damage and Trajectory

As shown in Figures 40 and 42, the 11 gage (0.1196 in. thick) steel pole was severely damaged. Upon impact, the pole buckled at the transverse weld joint 20 ft down from the top of the pole. No buckling occurred at the bottom transverse weld joint. In addition, as the mast arm and top of the pole impacted the ground, the pole buckled 10 ft down from the top of the pole. It appears as though the heat-affected zones of the transverse welds reduced the yield strength of the steel. In addition, the slight reduction of wall thickness of the pole in these areas, where the transverse welds are normally ground smooth for aesthetics before the pole is galvanized, also contributed to causing the buckling at the transverse welds. The pole was also badly buckled and torn at the mast arm-to-pole connection plates. There was also a slight dent in the pole where the initial bumper contact had occurred.

The lighting standard came to rest downstream from the pole foundation (Figure 40), with the pole base plate 54.6 ft downstream (south) and 5.2 ft east of the foundation. The tip of the pole was 20.4 ft south of the foundation. The mast arm, still undamaged and attached to the pole, rotated 180 degree from its original direction with its tip 15.2 ft west and 5.3 ft south of the pole foundation.

5.2.3.4 Luminaire Damage

The luminaire was totally demolished and slipped completely off the mast arm. The luminaire body landed 4 ft south of and 15.2 ft west of the pole foundation, away from traffic. The lens which was heavily taped before installation (to contain glass fragments) landed 4 ft south (downstream) and 4.8 ft east of the foundation, Figure 40. One piece of the cast aluminum cover landed 5.5 ft south of and 29.5 ft east of the pole foundation. Although this small piece would have landed in the traveled way, it probably would have caused little or no damage to cars in the outside lane.

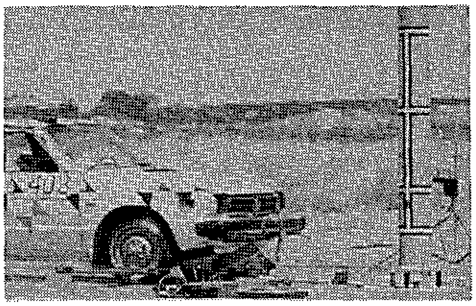
5.2.3.5 Vehicle Damage

Figure 43 shows the test vehicle after the impact. The crush profiles of the vehicle (measured in horizontal planes at different heights) are shown in Figure 44. The maximum crush of the bumper was 14.25 in.

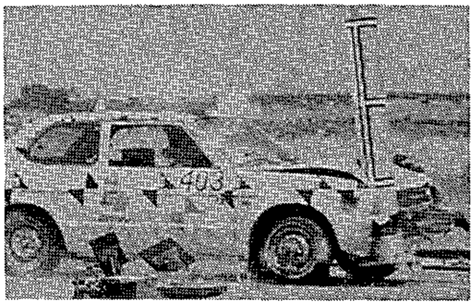
The radiator was pushed back to the engine block, but the engine did not move. The front frame members under the engine were also bent. The vehicle could not be driven away after the impact; however, it could be rolled away. There was no intrusion of vehicle or lighting standard components into the passenger compartment due to the impact.

5.2.3.6 Dummy Behavior

The test dummy, positioned in the driver's seat, was unrestrained. At the initial impact, the dummy's upper trunk and head were thrown forward and the head and chest came in contact with the steering wheel. After deceleration and the car brakes were applied, the dummy was found leaning slightly forward in the driver's seat.



0.018 Sec Before Impact



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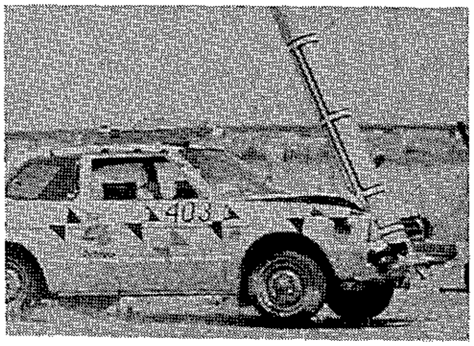

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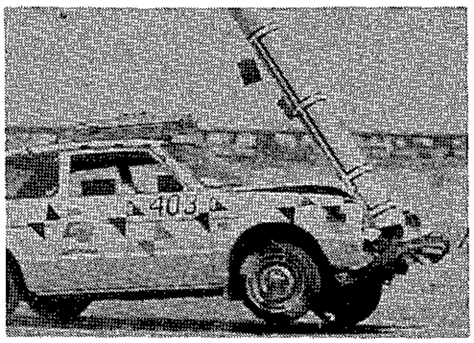
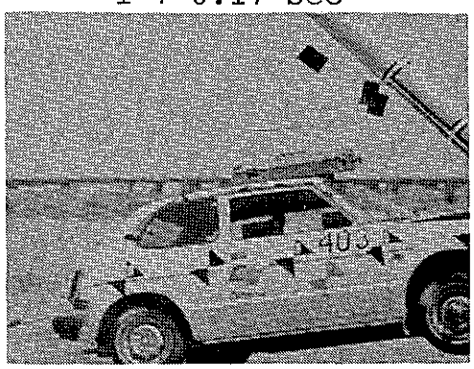


I + 0.17 Sec



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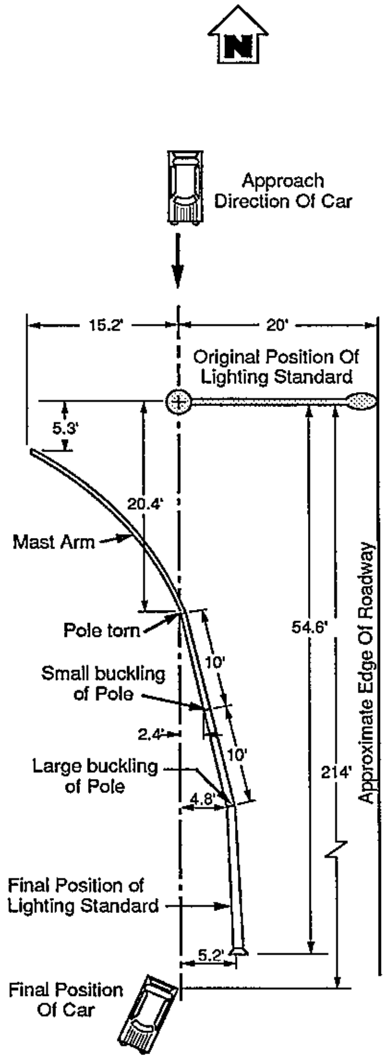


VEHICLE	1979 Honda Civic
VEHICLE WEIGHT (Including dummy & instrumentation)	2035 lb.
DUMMY RESTRAINT	None
IMPACT VELOCITY	59.1 Mph.
IMPACT LOCATION	9 1/2" Right of Centerline
OCCUPANT IMPACT VELOCITY.LONG.	12.4 fps
VEHICLE DAMAGE (measured at bumper ht.)	14-1/4"
VEHICLE ACCELERATION (max. 50 msec avg.)	
LATERAL	-2.13 g's
LONGITUDINAL	-5.78g's
VERTICAL	1.13 g's
HEAD INJURY CRITERION	8

TEST NO.	403
DATE	July 20, 1983
TYPE OF LIGHT STD.	Modified Type 31
POLE MATERIAL	Galvanized Steel
POLE DIMENSIONS	35'-0" x 10 1/16"O.D. x 5 3/8"O.D.
POLE BASE SLEEVE	0.1345" x 2'-0" High
MOUNTING HEIGHT	40'-3"
PROJECTED LENGTH OF MAST ARM	20'-0"
TOTAL WEIGHT	651 Lb.
BREAKAWAY DEVICE	Aluminum Couplings

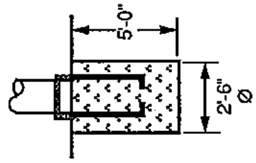


Figure 39. Test 403 Data Summary Sheet

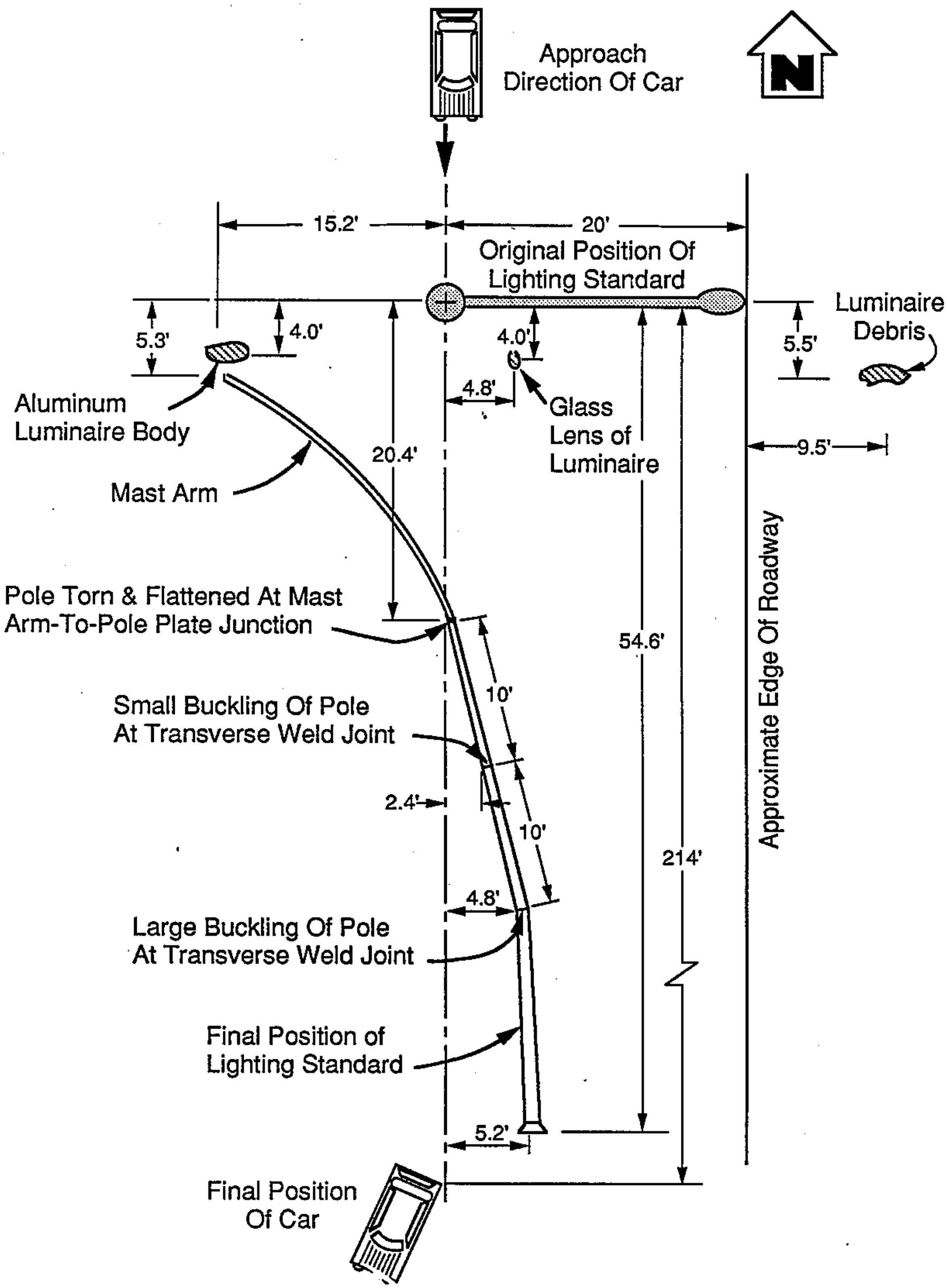


Figure 40. Final Location of the Lighting Standard and the Car After Collision - Test 403

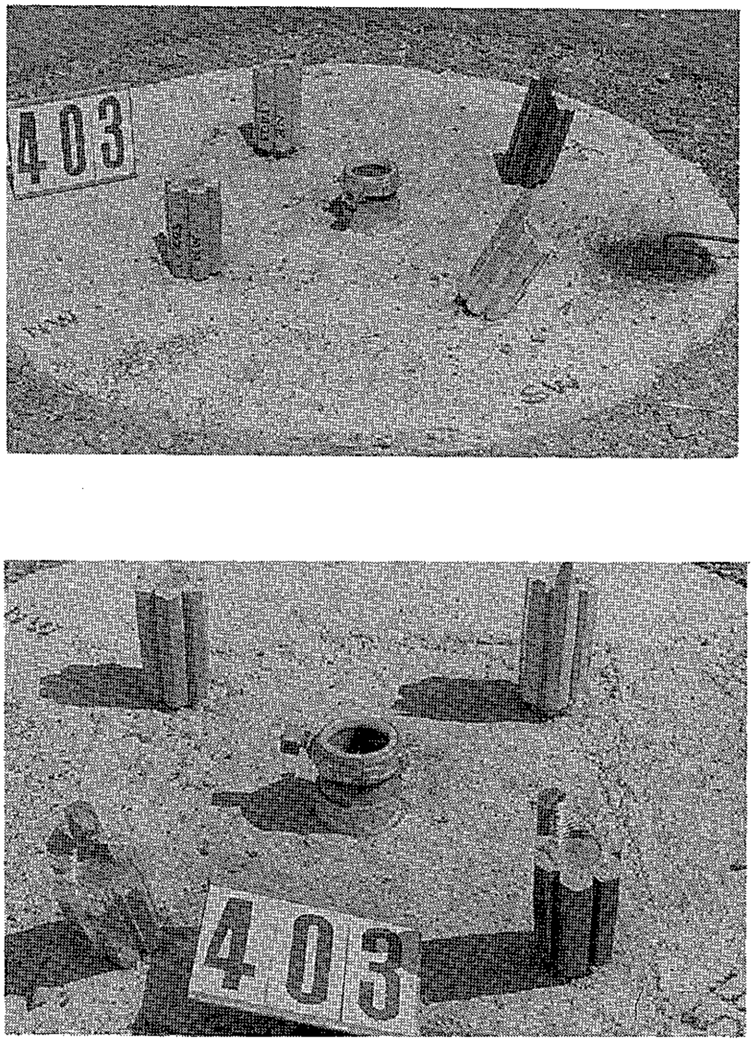


Figure 41. Die-cast Aluminum Couplings After Impact-Test 403

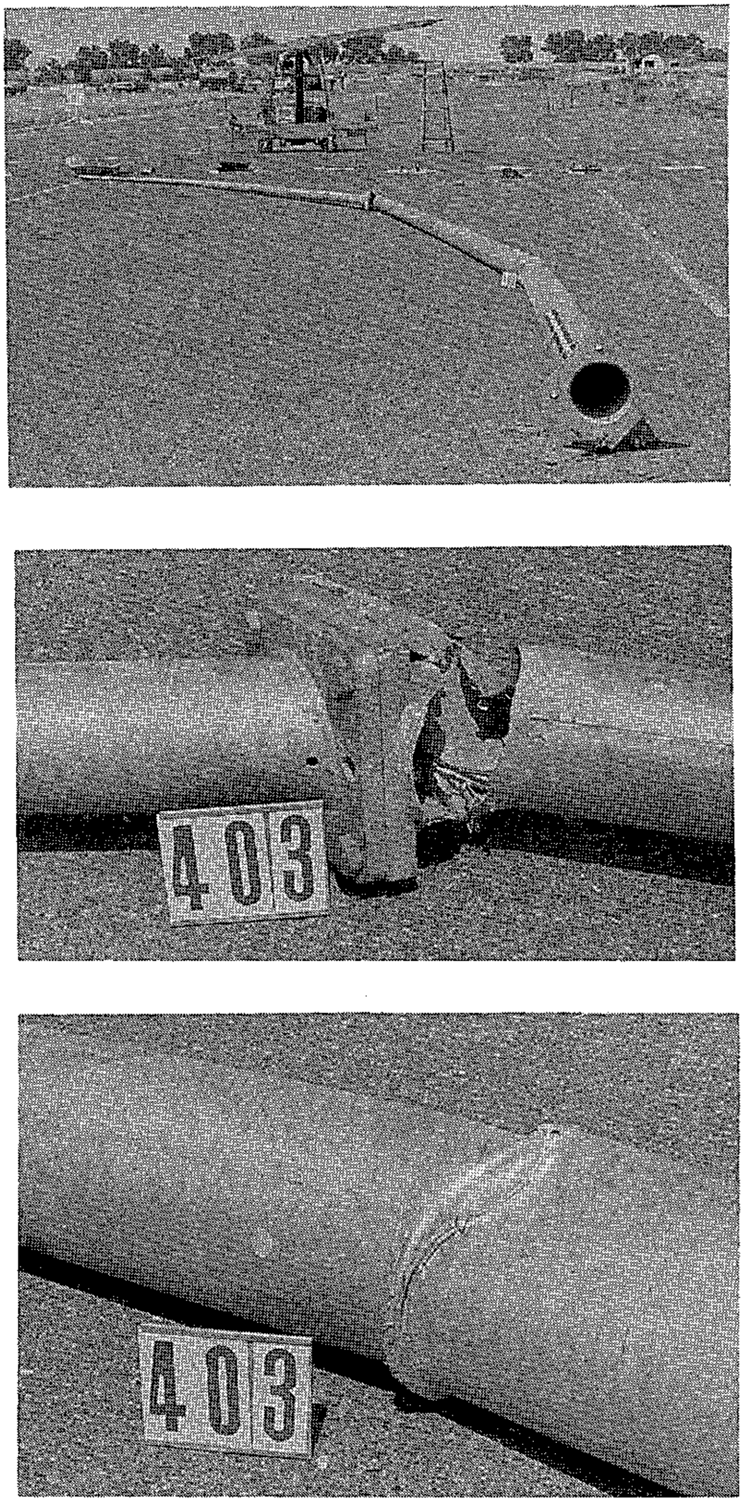


Figure 42. Lighting Standard Damage - Test 403

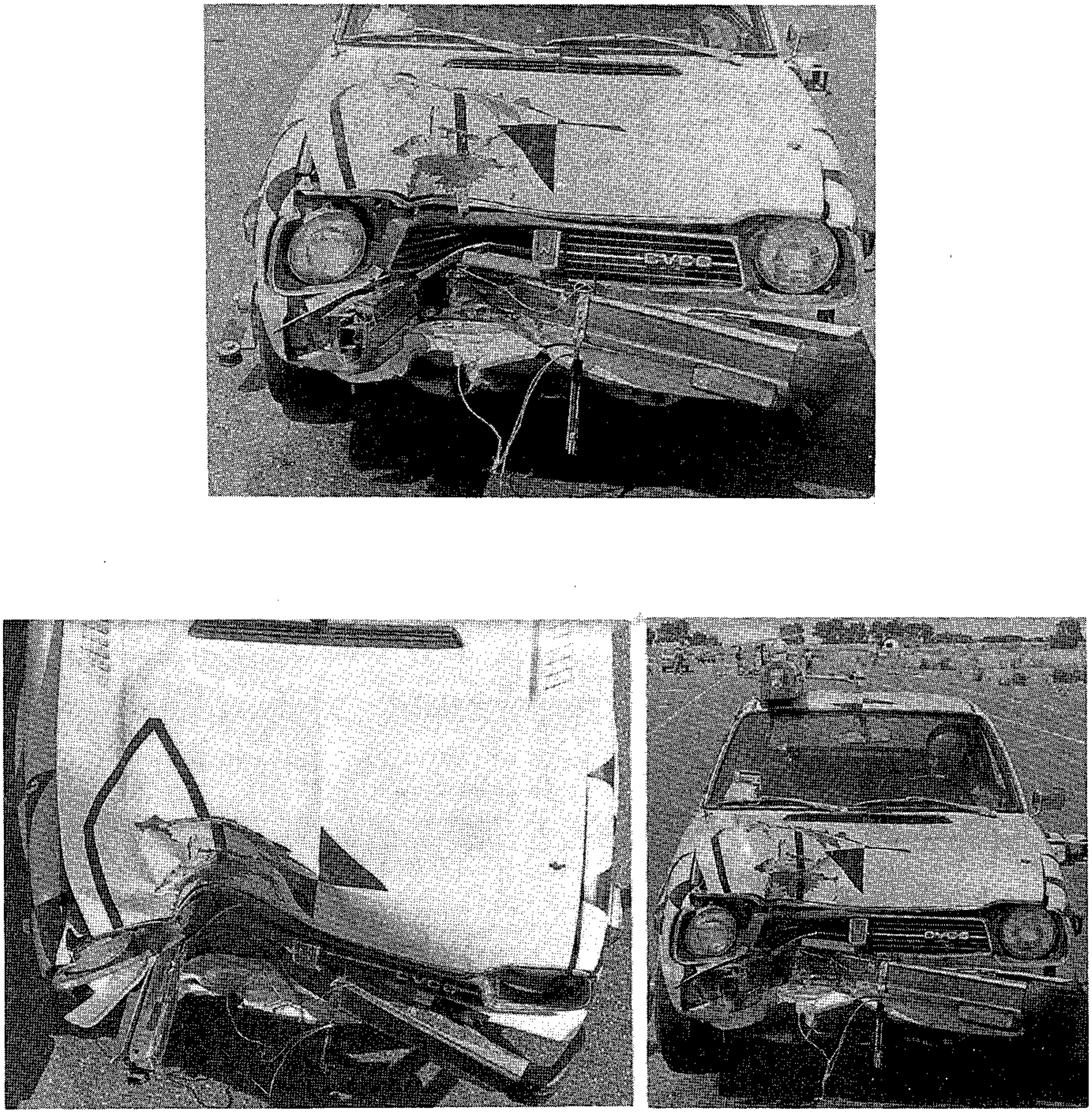


Figure 43. Test Vehicle After Impact - Test 403

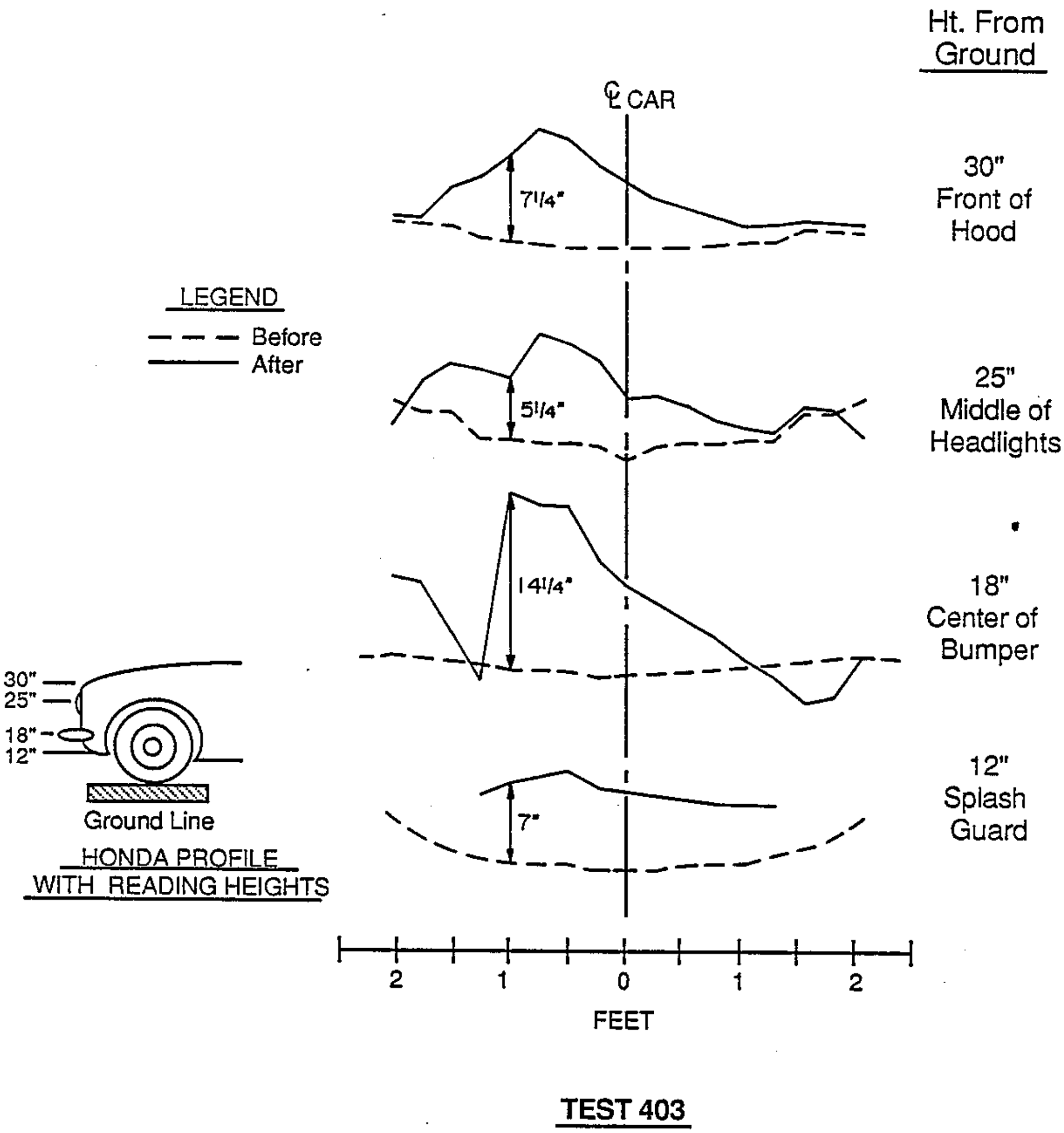


Figure 44. Crush Profiles of the Front End of Test Vehicle - Test 403

5.2.4 Test 404 - Standard Caltrans Type 31 Steel Lighting Standard with Standard Triangular Slip Base (1865-lb car/19.9 mph)

Test 404 was conducted according to procedures outlined for Test 62 of NCHRP Report 230, head-on at the center of bumper at 20 mph using an 1800-lb car with a dummy placed in the driver's seat. The objective was to determine if the Caltrans type 31 lighting standard (triangular slip base version, Figures 5, 6) would meet all requirements of NCHRP Test 62. The summary of test data and photos taken before, during, and after the impact are shown in Figure 45. Accelerometer data plots are shown in Figures C13 to C16 in Appendix C. This test and the next test, Test 405, serve as control tests by which the success of others in this series can be measured.

5.2.4.1 Impact Description

The 1979 Honda test vehicle impacted the base of the pole at the center of the front bumper. The impact speed was 19.9 mph. Upon impact, the slip base broke away and the car slowly pushed the pole base forward, where it bounced on the ground. The lower section of the pole then rolled over the car's roof, and slid off of the right rear quarter panel. The top of the pole swung down, hit the asphalt, and then the pole and mast arm came straight down on top of the foundation without any rotation. While the vehicle decelerated, it proceeded in a straight line without any yaw. The final position of the vehicle after brakes had been applied was 57.3 ft downstream, directly south of the foundation as shown in

Figure 46.

5.2.4.2 Lighting Standard Damage and Trajectory

The surface of the lower section of the galvanized steel pole where initial bumper impact occurred (18 in. from the ground to the center of the front bumper) was not dented or deformed. Minor damage was sustained at the top of the pole when it swung down and impacted the asphalt pavement, breaking the cast end cap into three large pieces and denting the back edge of the pole top as shown in Figure 47. The mast arm did not appear to be damaged and was still attached to the pole. The pole and mast arm were saved for use in crash Test 405 (60 mph).

After impact, the pole did not rotate and came to rest on top of the bottom slip base plate with its top 6.5 ft north of the concrete foundation (Figure 46). The tip of the mast arm projected about 1 ft into the outside traffic lane. Upon impact, the keeper plate which was installed at the slip plane, ripped open at two corners, and was carried downstream approximately 14 ft, still retaining one of the clamping bolts. The other two clamping bolts were nearby. No relative movement between the concrete foundation and the surrounding soil backfill was evident.

5.2.4.3 Luminaire Damage

Immediately upon impact, the luminaire shook loose from the mast arm tip and fell to the ground as a unit. It was badly damaged after hitting the ground. The luminaire body and miscellaneous parts of the luminaire housing landed about 23.5 ft east and 22.5

ft north of the original foundation as shown in Figure 46.

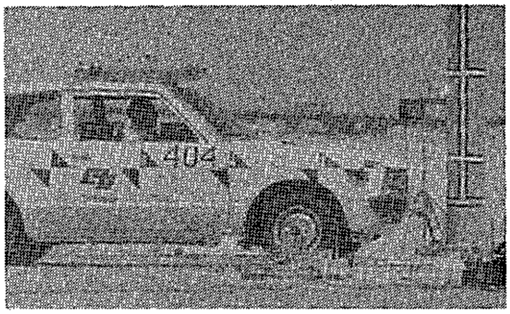
5.2.4.4 Vehicle Damage

Figure 48 shows the test vehicle after the impact. The crush profiles of the vehicle (measured in horizontal planes at different heights) are shown in Figure 49. The maximum crush of the front bumper was 11 in.

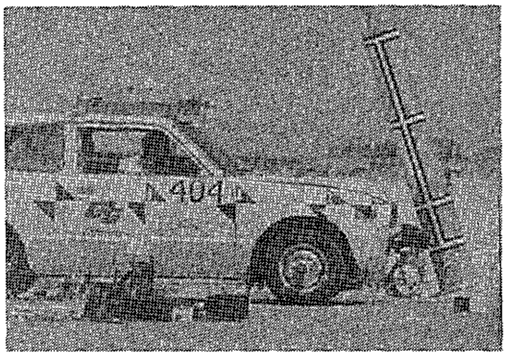
The radiator was pushed back to the fan, but the engine did not move. The vehicle could not be driven away after the impact; however, it could be rolled away. There was no intrusion of vehicle or lighting standard components into the passenger compartment due to the impact.

5.2.4.5 Dummy Behavior

The test dummy, positioned in the driver's seat during the impact, was unrestrained. Upon impact, the dummy bent at the waist, with its upper trunk being accelerated forward and its face and nose hitting the top of the steering wheel. The impact data on the dummy indicates that a human driver probably would have survived the crash with only minor injuries.



0.02 Sec Before Impact



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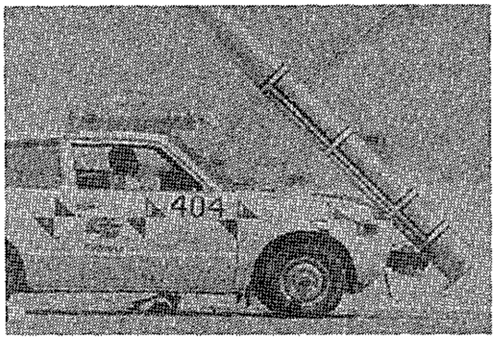

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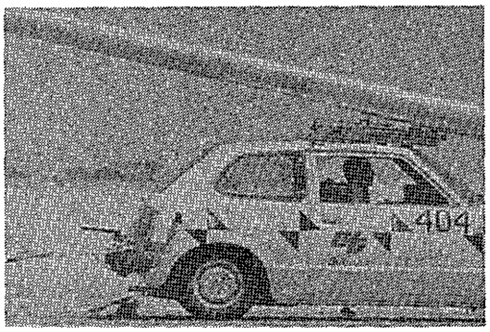
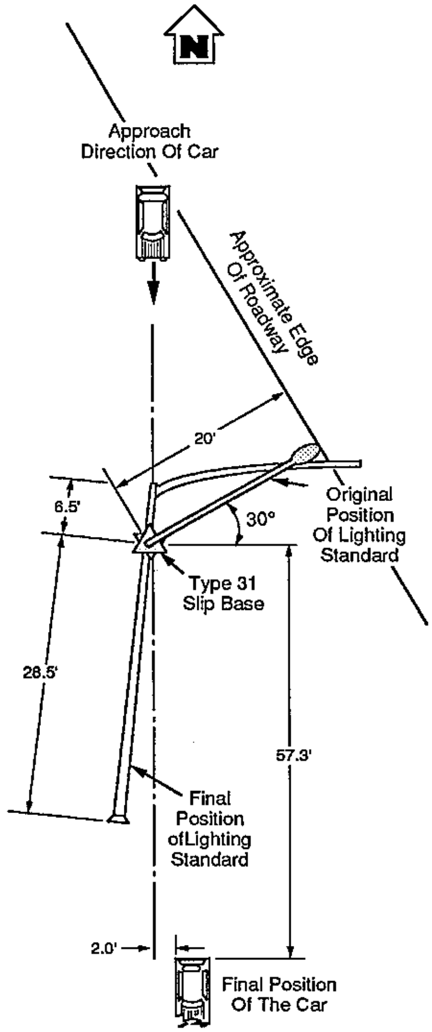


I + 0.5 Sec

I + 0.57 Sec



TEST NO.	404
DATE	July 26, 1984
TYPE OF LIGHT STD.	Caltrans Type 31
POLE MATERIAL	Galvanized Steel
POLE DIMENSIONS	35'-0" x 10.7/8"O.D. x 6"O.D.
POLE BASE SLEEVE	None
MOUNTING HEIGHT	37'-0"
PROJECTED LENGTH OF MAST ARM	20'-0"
TOTAL WEIGHT	883 Lbs.
BREAKAWAY DEVICE	Type 31 Triangular Slip base

VEHICLE	1979 Honda Civic
VEHICLE WEIGHT (Including dummy & instrumentation)	2015 lb.
DUMMY RESTRAINT	None
IMPACT VELOCITY	19.9 Mph.
IMPACT LOCATION	Center of the Front Bumper
OCCUPANT IMPACT VELOCITY LONG.	8.5 fps
VEHICLE DAMAGE (measured at bumper ht.)	11"
VEHICLE ACCELERATION (max. 50 msec avg.)	
LATERAL	-0.87 g's
LONGITUDINAL	-5.44 g's
VERTICAL	-0.81 g's
HEAD INJURY CRITERION	10

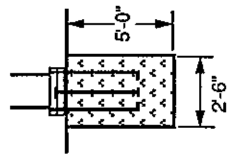
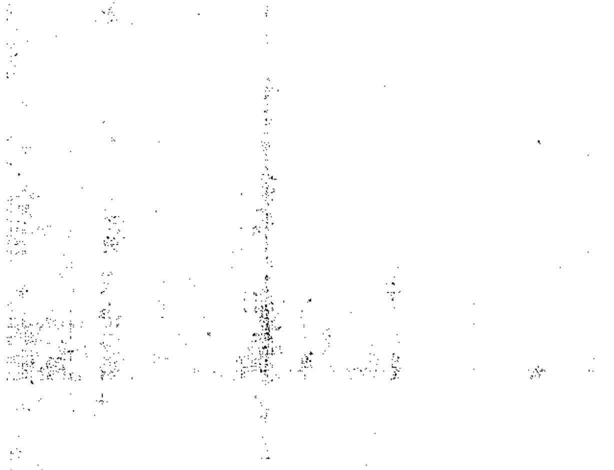
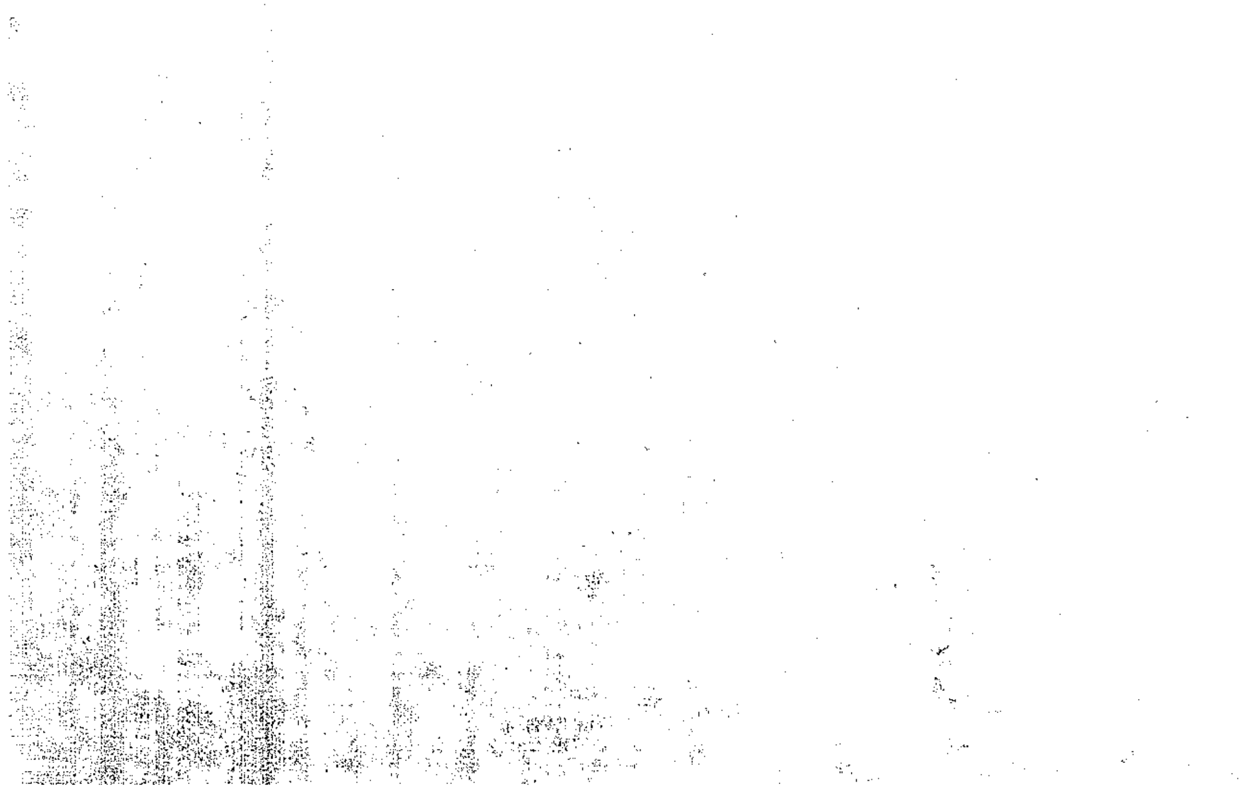


Figure 45. Test 404 Data Summary Sheet





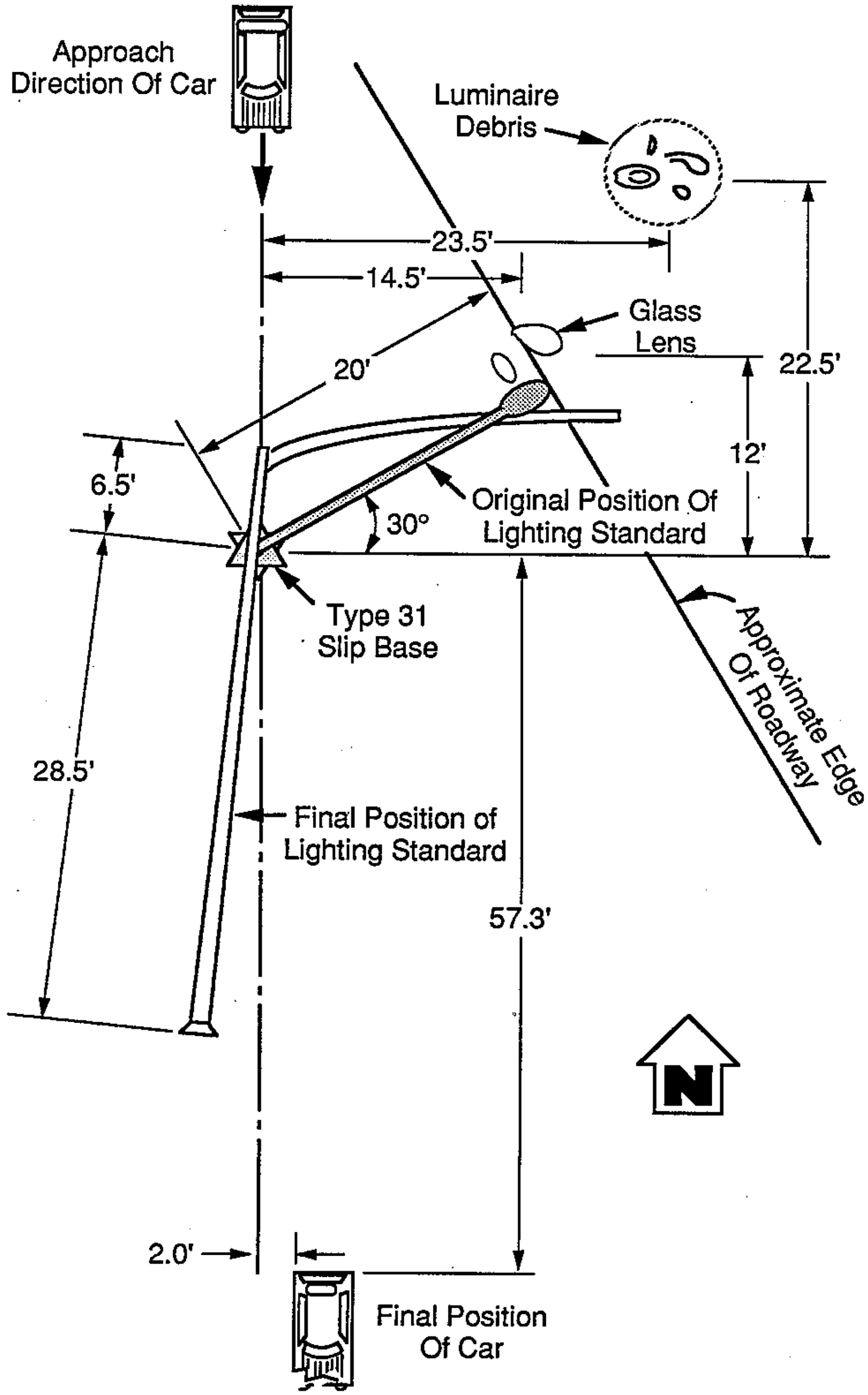
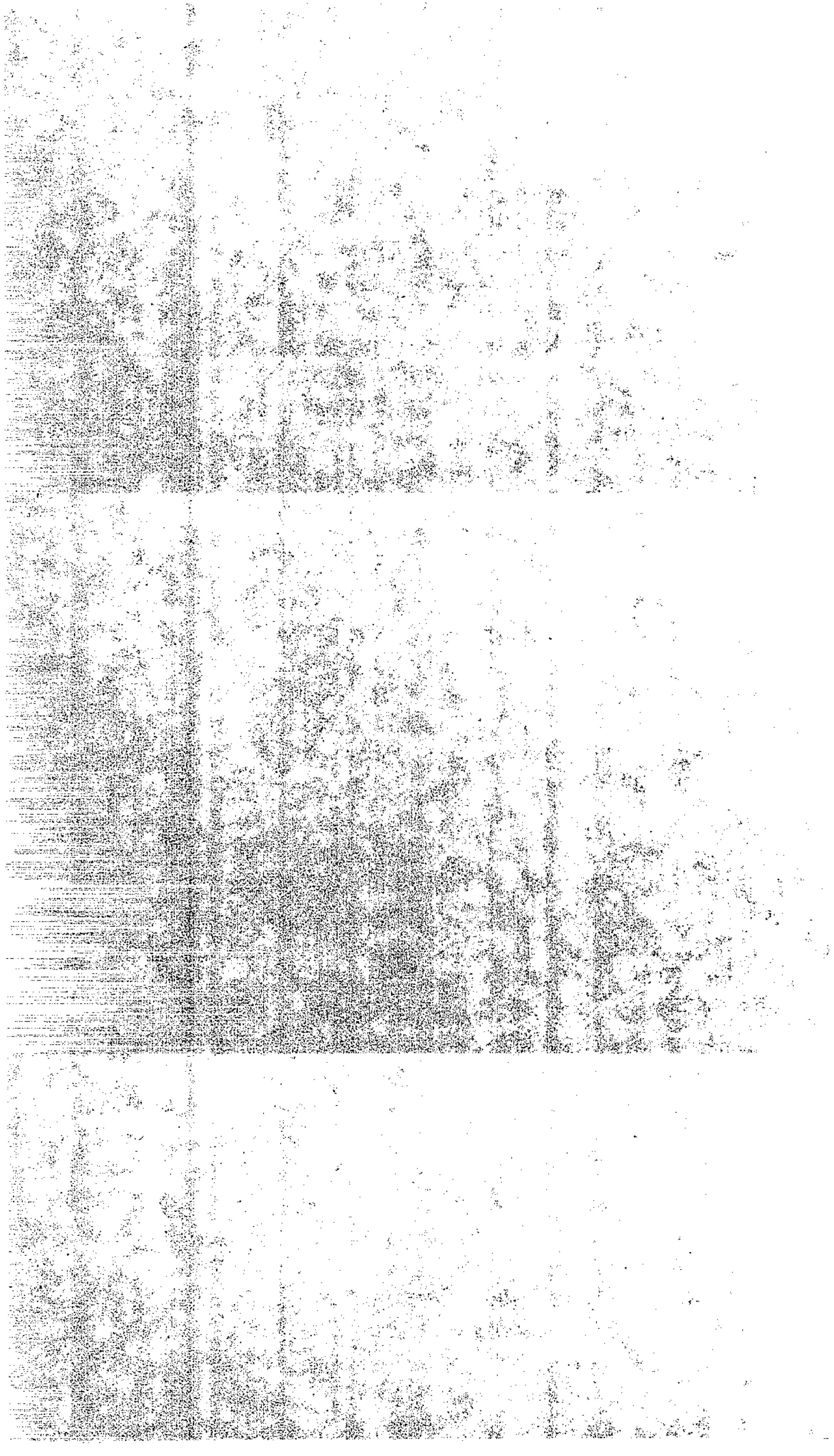


Figure 46. Final Location of the Lighting Standard and the Car After Collision - Test 404



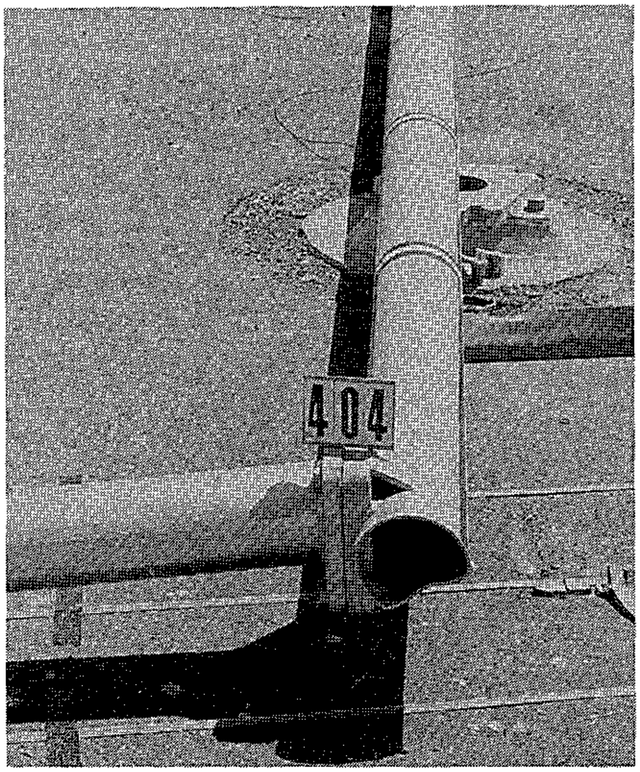


Figure 47. Lighting Standard Damage - Test 404

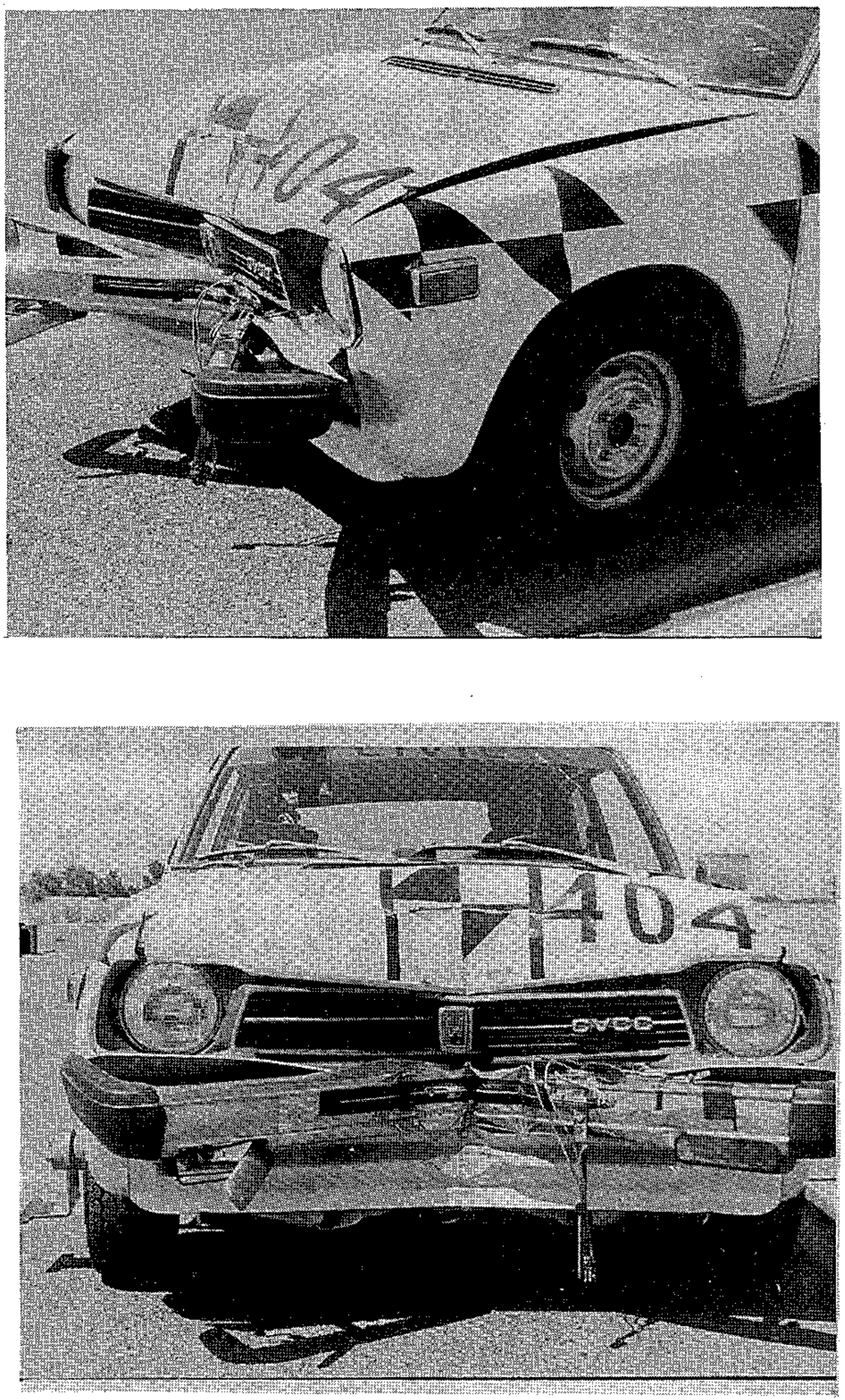


Figure 48. Test Vehicle After Impact - Test 404

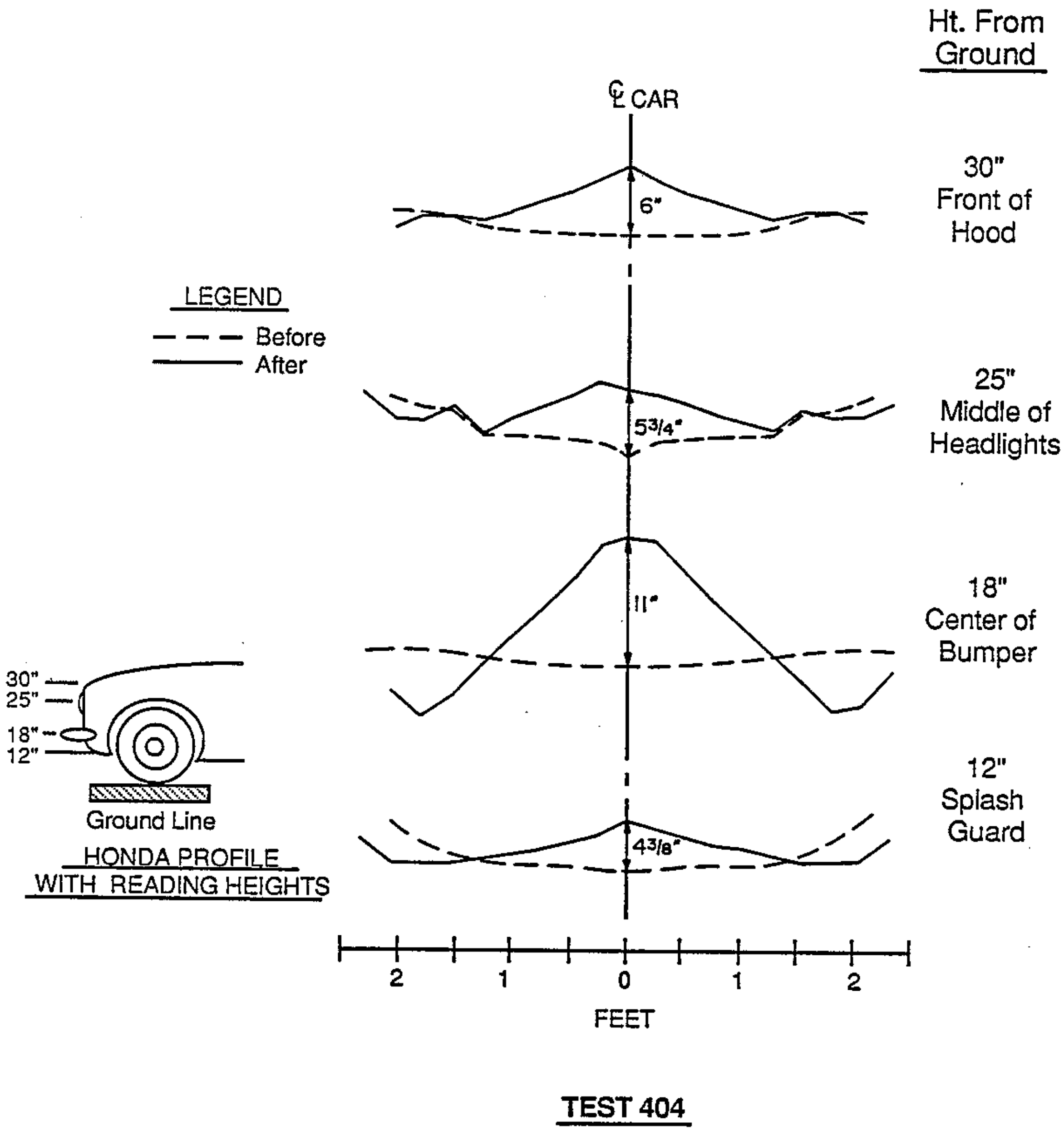


Figure 49. Crush Profiles of the Front End of Test Vehicle - Test 404

5.2.5 Test 405 - Standard Caltrans Type 31 Steel Lighting Standard with Standard Triangular Slip Base (1885-lb car/53.9 mph)

Test 405 was conducted according to procedures outlined for Test 63 of NCHRP Report 230, head-on at the quarter point of the bumper at 60 mph using an 1800-lb car with a dummy placed in the driver's seat. The objective was to determine if the Caltrans type 31 lighting standard (triangular slip base version, Figures 5, 6) would meet all requirements of NCHRP Test 63. The summary of test data and photos taken before, during, and after the impact are shown in Figure 50. Accelerometer data plots are shown in Figures C17 to C20 in Appendix C.

5.2.5.1 Impact Description

The 1979 Honda test vehicle first impacted the base of the pole 13-5/8 in. to the right of center line of the vehicle's front bumper (1-3/8 in. to the left of the desired quarter point location). The impact speed was 53.9 mph (an impact speed of 60 mph was desired). Since the initial impact was offset from the Honda's c.g., the car yawed immediately after impact, and both the right front and the right rear tires ran over the foundation and bottom slip base plate assembly which was bolted to the foundation. Running over the foundation caused the whole right side of the Honda to vault into the air. After the initial 40 degree clockwise yaw, the car proceeded southwest in a fairly straight line until coming to rest 200 ft south and 72 ft west of the pole foundation as shown in Figure 51.

5.2.5.2 Lighting Standard Damage and Trajectory

The lower section of the galvanized steel pole sustained no damage from the impact of the vehicle's bumper. The surface of the pole where initial bumper impact occurred (18 in. from the ground to the center of the front bumper) was not dented or deformed. After impact, the pole base was quickly accelerated and was kicked up high enough so the decelerating Honda had no problem passing beneath the pole base without further contact. The top of the pole swung down and impacted the asphalt pavement, breaking the end cap and denting the back edge of the pole top as shown in Figure 52. This also bowed the pole resulting a chord offset of 6-1/2 in. at a distance of 20 ft from the bottom of the pole. The mast arm was bowed slightly and was still attached to the pole.

Figure 51 is the schematic representation of the lighting standard damage and final location. As shown, the top of the pole came to rest 6 ft downstream from the concrete foundation. The tip of the mast arm came to rest 19.5 ft due east of the foundation, pointing toward the traffic lanes. Upon impact, the keeper plate which was installed at the slip plane ripped open at the front corner as designed, and was carried downstream, retaining the two rear clamping bolts. It came to rest approximately 12.5 ft west and 105 ft south of the foundation. The pole end cap and portions of the luminaire housing landed about 27 ft east of the foundation. No relative movement between the concrete foundation and the surrounding soil backfill was evident.

5.2.5.3 Luminaire Damage

The luminaire housing exploded from shock, just after the car hit the pole base. Major pieces of the broken luminaire housing and the glass lens (fully taped to avoid making an unnecessary mess) were found scattered from 25 to 35 ft east of the foundation.

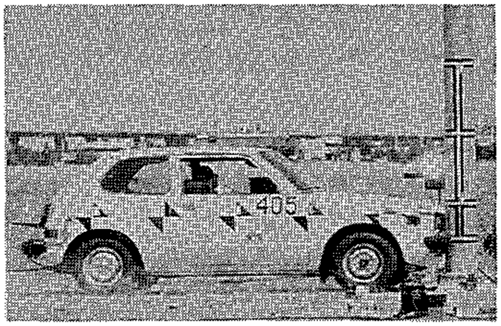
5.2.5.4 Vehicle Damage

Figure 53 shows the test vehicle after the impact. The front crush profiles of the vehicle (measured in horizontal planes at different heights) are shown in Figure 54. The maximum crush of the bumper was 13-5/8 in.

The radiator was pushed back to the fan, but the engine did not move. The right front fender was severely crushed and the front frame members under the engine were also bent. The vehicle could not be driven away after the impact; however, it could be rolled away. There was no intrusion of vehicle or lighting standard components into the passenger compartment due to the impact.

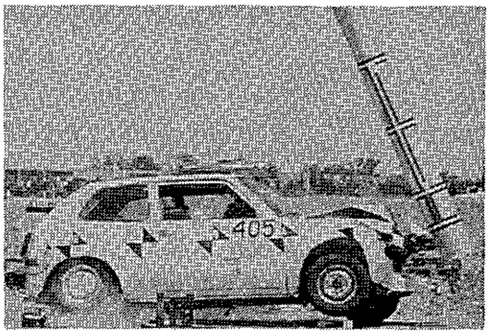
5.2.5.5 Dummy Behavior

The anthropomorphic dummy, positioned in the driver's seat, was unrestrained. There was no internal film coverage of the dummy during and after impact because the camera switch was unintentionally cut off just before impact. Other test data (dummy accelerometer and HIC data are shown in the data summary sheet, (Figure 50); however, indicate that injuries to the dummy would have been minor.

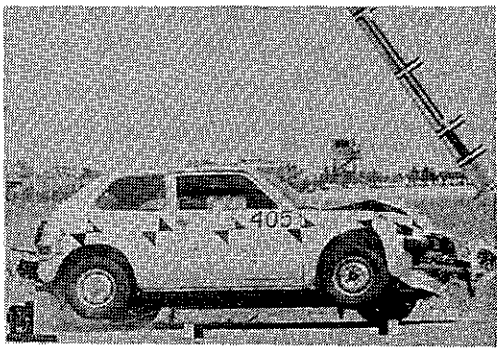


Impact + 0.003 Sec

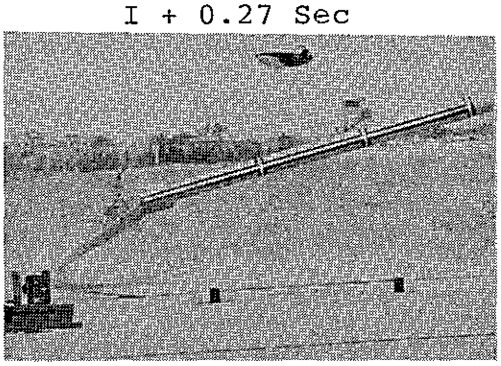
I + 0.11 Sec



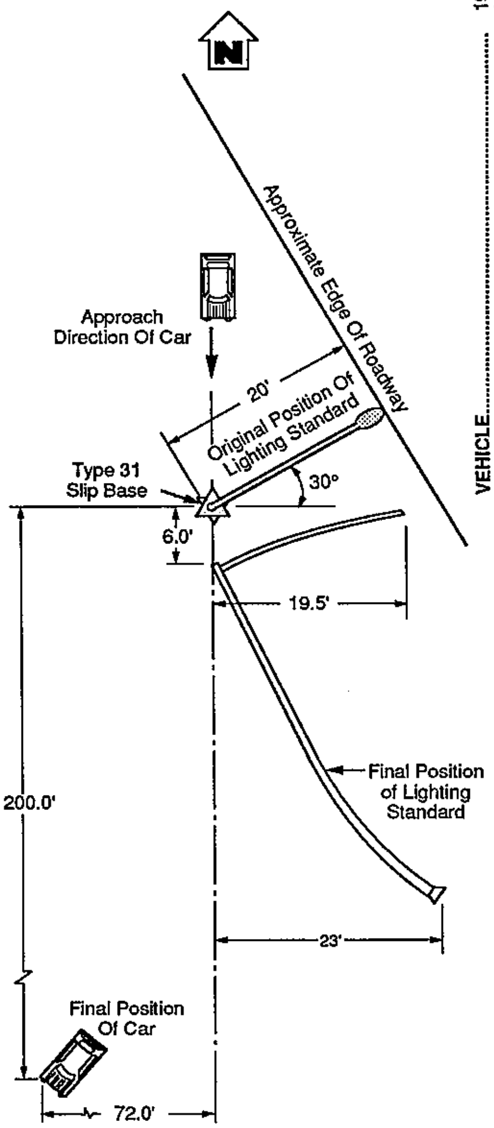
I + 0.17 Sec

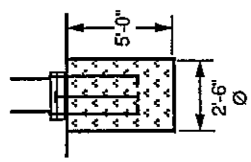


I + 0.27 Sec



I + 0.75 Sec





TEST NO.	405
DATE	May 23, 1985
TYPE OF LIGHT STD.	Caltrans Type 31
POLE MATERIAL	Galvanized Steel
POLE DIMENSIONS	35'-0" x 10 7/8"O.D. x 6"O.D
POLE BASE SLEEVE	None.
MOUNTING HEIGHT	37'-0"
PROJECTED LENGTH OF MAST ARM	20'-0"
TOTAL WEIGHT	883 Lb.
BREAKAWAY DEVICE	Type 31 Triangular Slip base

VEHICLE	1979 Honda Civic
VEHICLE WEIGHT (Including dummy & instrumentation)	2050 lb.
DUMMY RESTRAINT	None
IMPACT VELOCITY	53.9 Mph.
IMPACT LOCATION	13-5/8" Right of Centerline
OCCUPANT IMPACT VELOCITY LONG.	12.4 fps
VEHICLE DAMAGE (measured at bumper ht.)	13-5/8"
VEHICLE ACCELERATION (max. 50 msec avg.)	
LATERAL	-1.64 g's
LONGITUDINAL	-7.24g's
VERTICAL	1.36 g's
HEAD INJURY CRITERION	8

Figure 50. Test 405 Data Summary Sheet

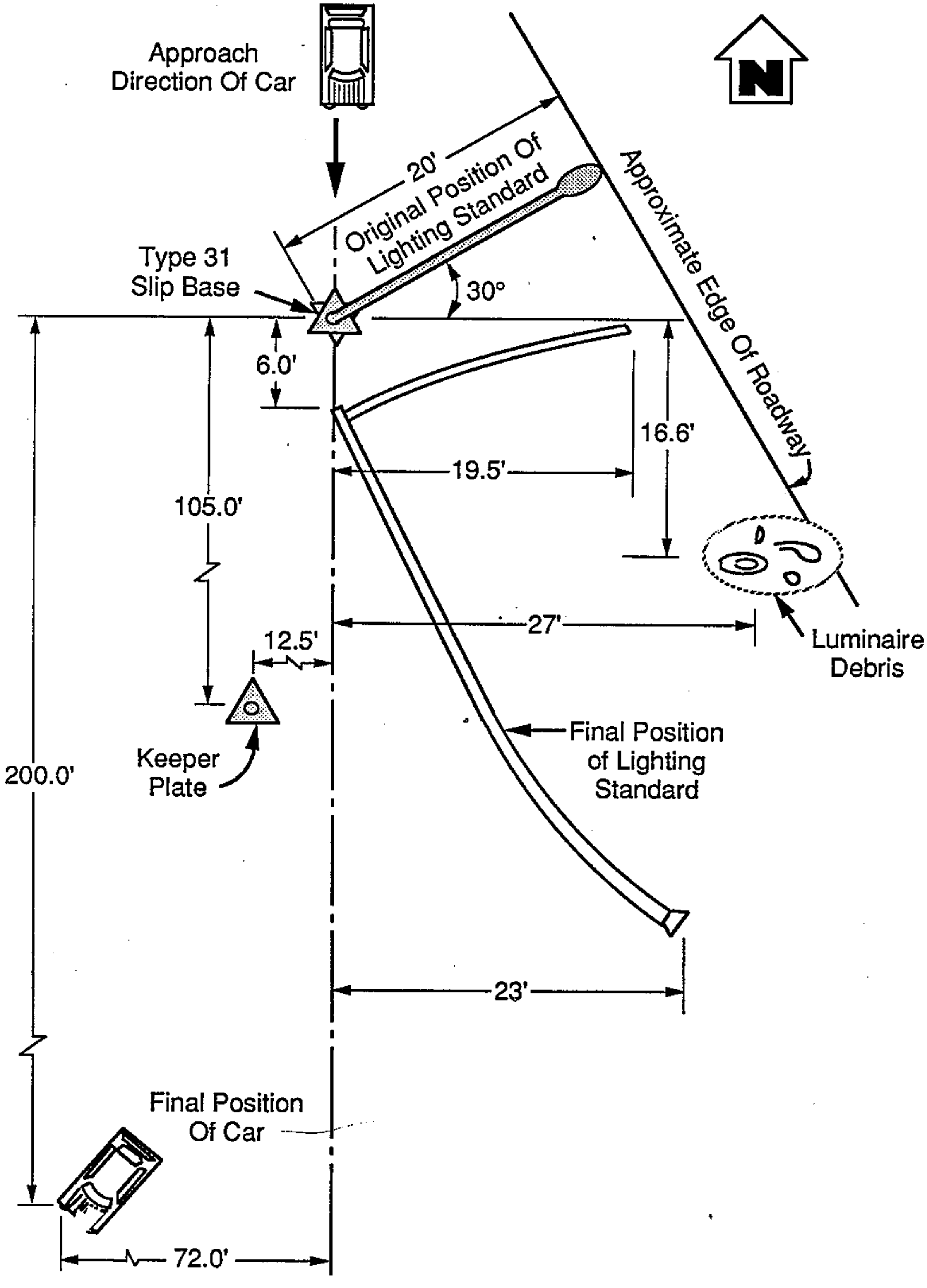


Figure 51. Final Location of the Lighting Standard and the Car After Collision - Test 405

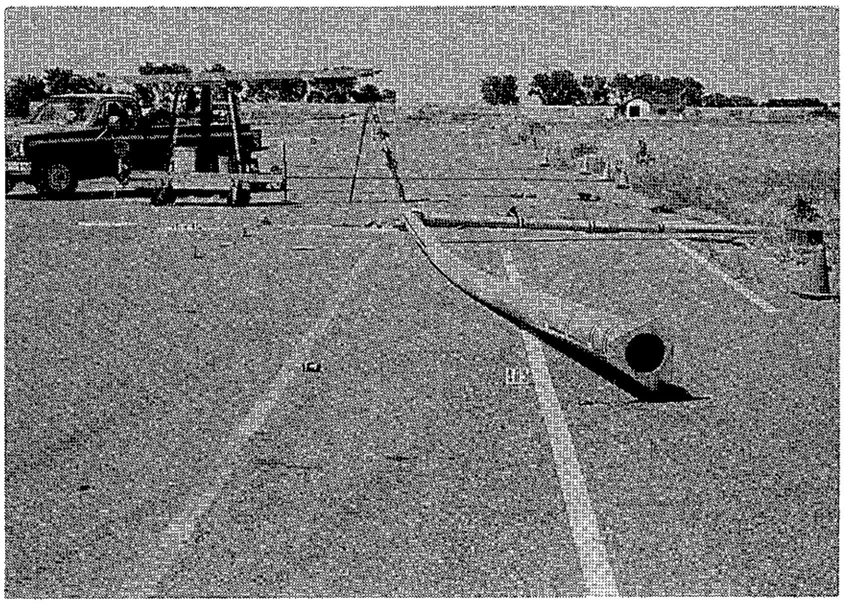


Figure 52. Lighting Standard Damage - Test 405

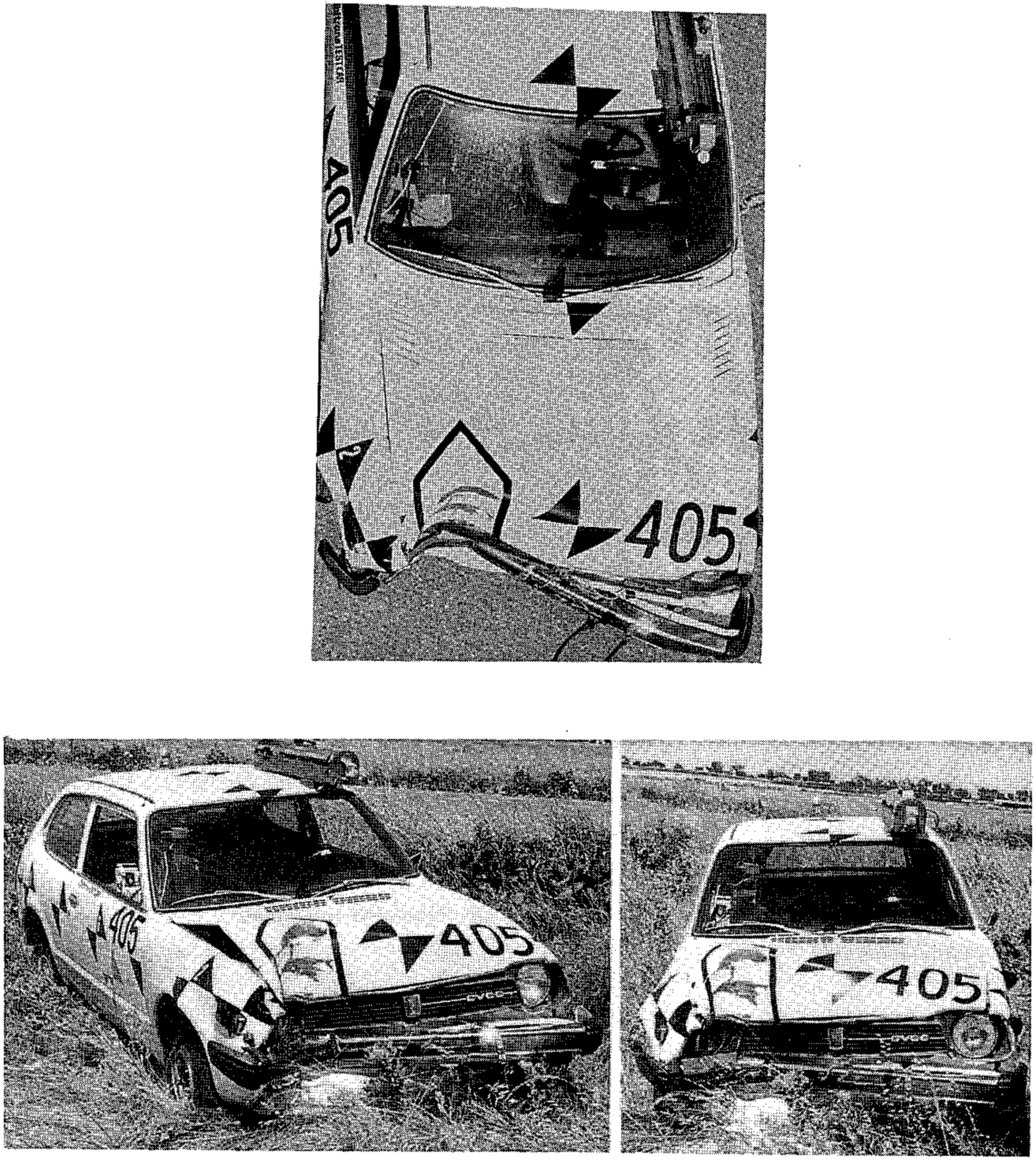


Figure 53. Test Vehicle After Impact - Test 405

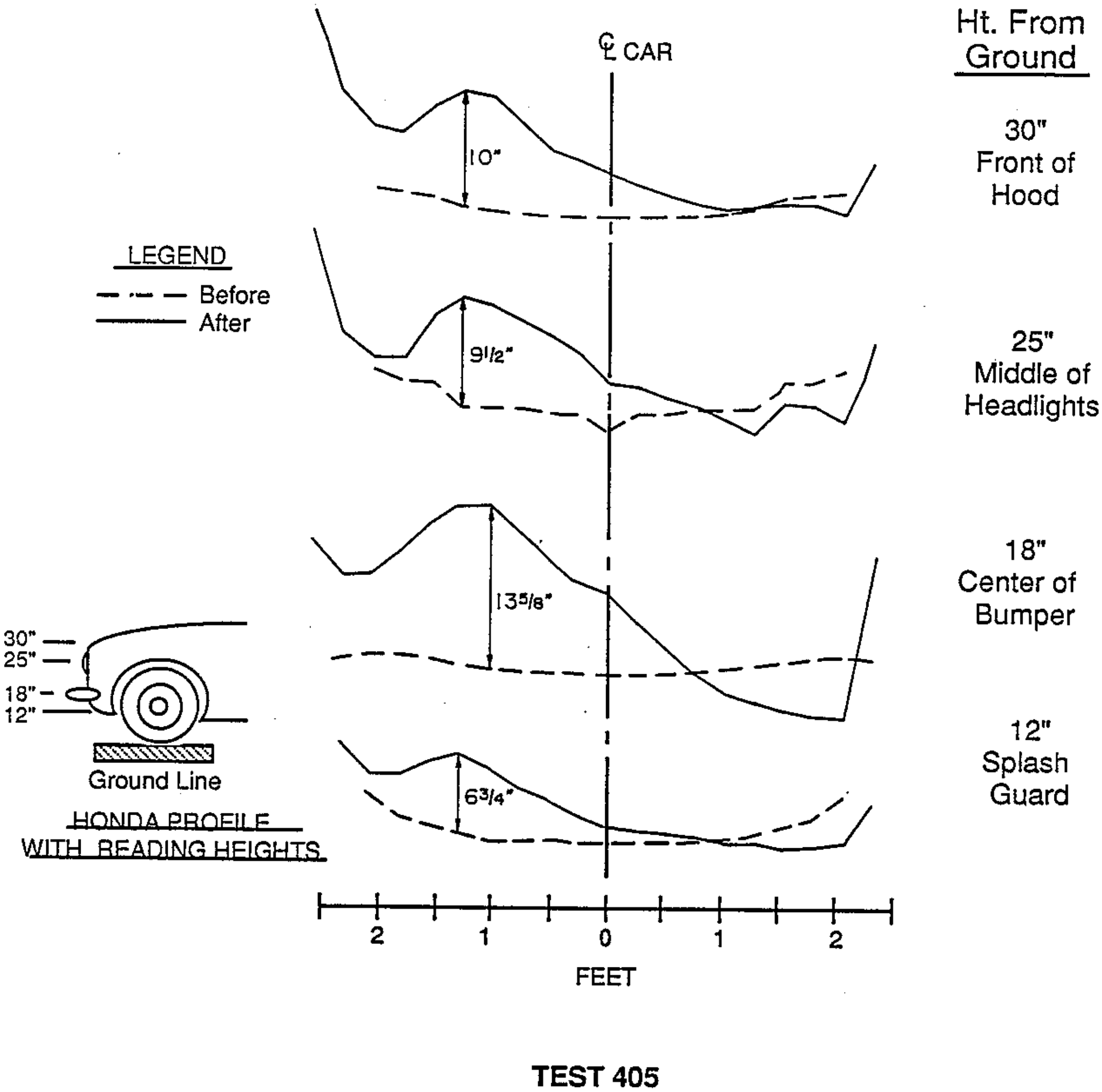


Figure 54. Crush Profiles of the Front End of Test Vehicle - Test 405

5.2.6 Test 406 - Modified Type 31 Steel Lighting Standard with Standard Triangular Slip Base (1850-lb car/58.8 mph)

Test 406 was conducted according to procedures outlined for Test 63 of NCHRP Report 230, head-on at the quarter point of the bumper at 60 mph using an 1800-lb car with an unrestrained dummy placed in the driver's seat. The objective was to determine if a modified Caltrans type 31 steel lighting standard made from a thinner gage steel (as explained in section 5.1.2.1, 2, Figure 4) and equipped with a standard triangular slip base would meet all requirements of NCHRP Test 63. The summary of test data and photos taken before, during, and after the impact are shown in Figure 55. Accelerometer data plots are shown in Figures C21 to C24 in Appendix C.

5.2.6.1 Impact Description

The vehicle impacted the pole 18-3/4 in. to the right of the centerline of the front bumper (15 in. desired) at 58.8 mph. Upon impact, the pole base was pushed up and over the roof of the decelerating vehicle without contacting the roof. As in crash Test 405, both the right front and right rear tires of the Honda ran over the grout pad and bottom slip base assembly which was bolted to the top of the foundation. This seemed to loft the whole right side of the car into the air just after the right rear tire cleared the foundation. This off-centered hit caused a substantial clockwise yaw (approximately 30 degrees) just after impact; however, the car seemed to straighten out after traveling a short distance further. As the brakes were applied, the car began skidding and yawing to the left in the opposite direction, and finally came to rest pointing almost due west, 167.1 ft downstream from and 7.3 ft to the west of the foundation as shown in Figure 56.

5.2.6.2 Lighting Standard Damage and Trajectory

The surface of the pole where initial bumper impact occurred (18 in. from the ground to the center of the front bumper) was not dented or deformed. The lower section of the galvanized steel pole sustained no significant damage from the impact of the vehicle bumper and front end. After impact, the pole tip and the mast arm swung down and impacted the asphalt concrete pavement, breaking the end cap and flattening the back edge of the pole top. The mast arm buckled approximately 6 in. from the mast arm-to-pole end plate (Figure 57) and the pole had a slight permanent bow about 15 ft from its tip.

The base of the pole was carried downstream and came to rest 50 ft from the foundation, as shown on Figure 56. The tip of the mast arm came to rest approximately 10 ft east and 1.8 ft south of the foundation and was pointed northeast, toward traffic lanes. The keeper plate was found 205 ft downstream (south) of the foundation with each of the three corners ripped open. No relative movement between the concrete foundation and the surrounding soil backfill was evident.

5.2.6.3 Luminaire Damage

At initial impact of the car and the pole base, the luminaire exploded from the impact shock at the end of the mast arm. Various parts of the luminaire, then, came raining down. Remnants of the luminaire housing landed 30 ft east and 43 ft south of the original foundation which would be outside of the traffic lanes.

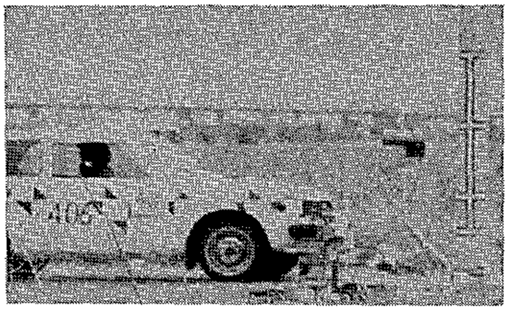
5.2.6.4 Vehicle Damage

Figure 58 shows the test vehicle after the impact. The front crush profiles of the vehicle (measured in horizontal planes at different heights) are shown in Figure 59. The maximum crush of bumper was 15-1/8 in.

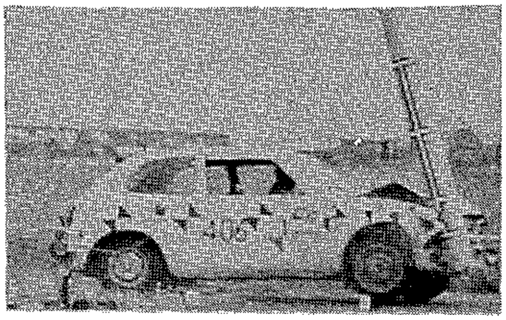
The radiator was pushed back to the fan, but the engine did not move. The left door was jammed, the right front fender was severely crushed to the front tire, and the front frame members under the engine were bent. The vehicle could neither be driven nor rolled away after the impact. There was no intrusion of vehicle or lighting standard components into the passenger compartment due to the impact.

5.2.6.5 Dummy Response

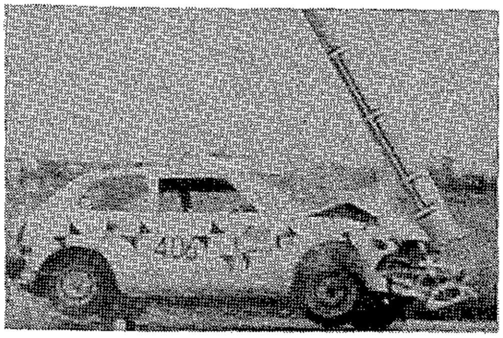
The test dummy, positioned in the driver's seat was unrestrained. There was no internal camera coverage for the dummy due to a shortage of high-speed cameras. Upon initial impact, the dummy bent at the waist and the shoulders and head were thrown forward. The dummy's head hit the steering wheel. Figure 60 shows the dummy's position after the impact.



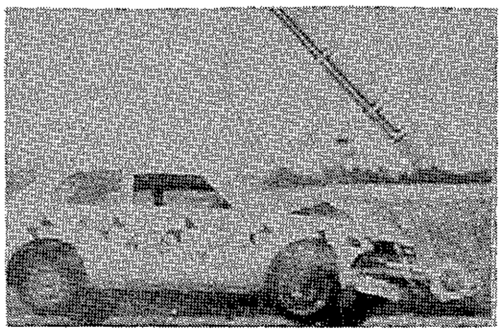
0.05 Sec Before Impact



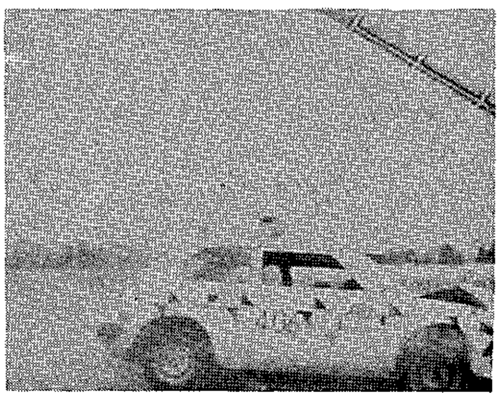
I + 0.05 Sec



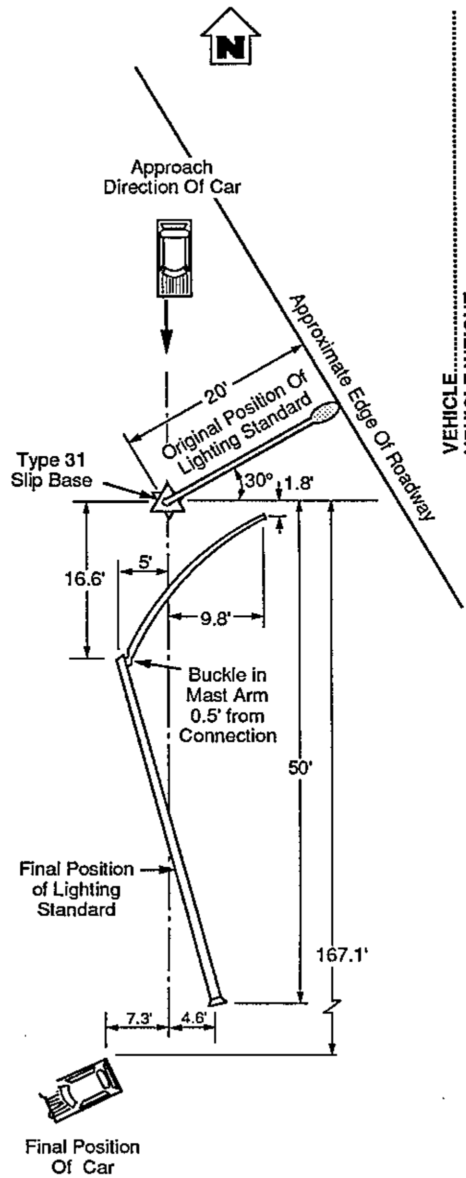
I + 0.15 Sec



I + 0.2 Sec



I + 0.31 Sec



VEHICLE	1979 Honda Civic
VEHICLE WEIGHT (including dummy & instrumentation)	2015 lb.
DUMMY RESTRAINT	None
IMPACT VELOCITY	58.8 Mph.
IMPACT LOCATION	18-3/4" Right of Centerline
OCCUPANT IMPACT VELOCITY LONG.	13 fps
VEHICLE DAMAGE (measured at bumper ht.)	15-1/8"
VEHICLE ACCELERATION (max. 50 msec avg.)	
LATERAL	-1.49 g's
LONGITUDINAL	-7.16 g's
VERTICAL	-1.64 g's
HEAD INJURY CRITERION	7

TEST NO.	406
DATE	May 8, 1987
TYPE OF LIGHT STD.	Modified Type 31
POLE MATERIAL	Galvanized Steel
POLE DIMENSIONS	33'-0" x 10" O.D. x 5-3/8" O.D.
THICKENED POLE BASE	2'-0" x 10" O.D. x 0.25"
MOUNTING HEIGHT	39'-3"
PROJECTED LENGTH OF MAST ARM	20'-0"
TOTAL WEIGHT	627.4 Lb.
BREAKAWAY DEVICE	Type 31 Triangular Slip base

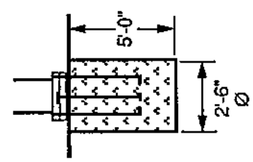
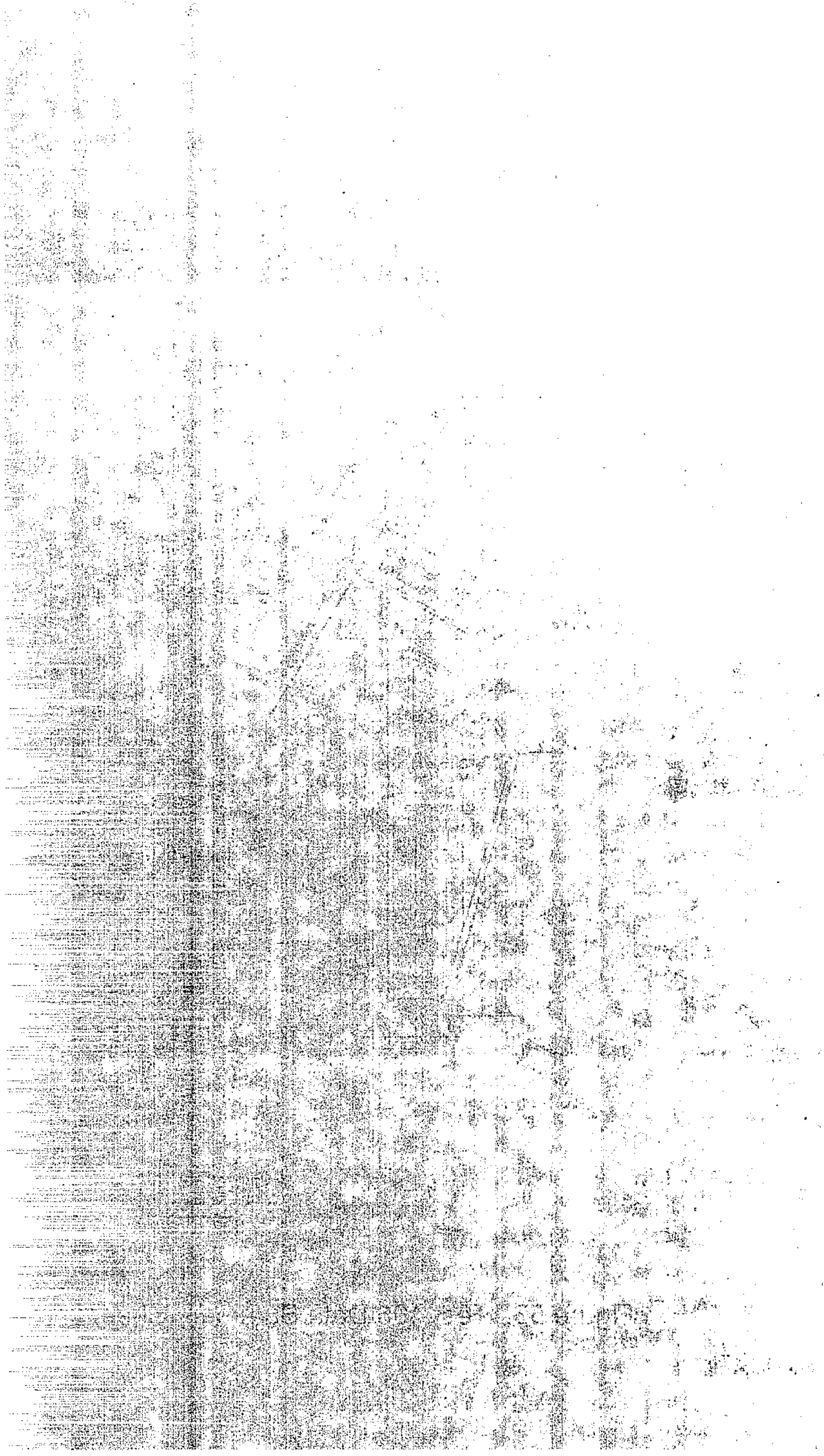


Figure 55. Test 406 Data Summary Sheet



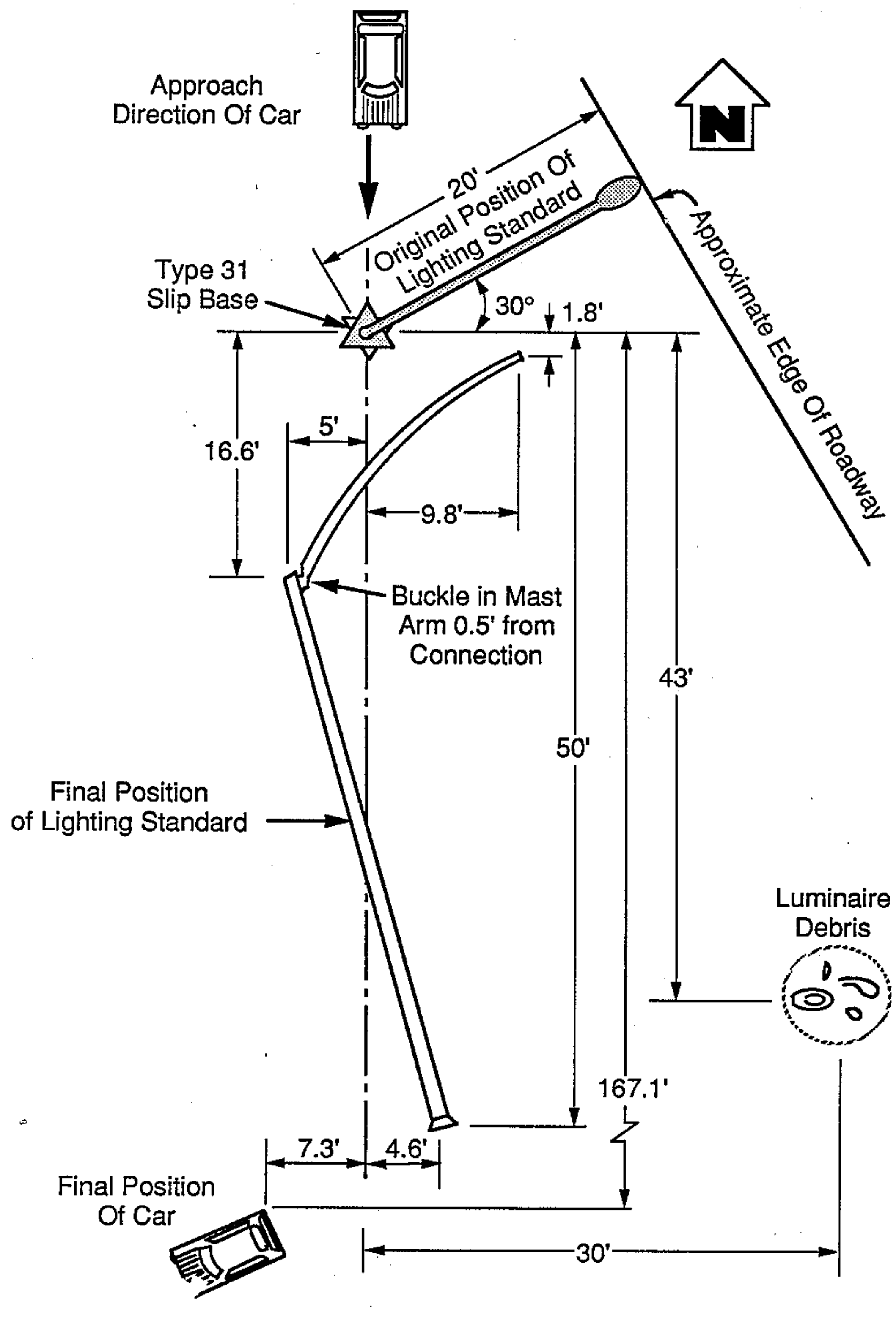


Figure 56. Final Location of the Lighting Standard and the Car After Collision - Test 406

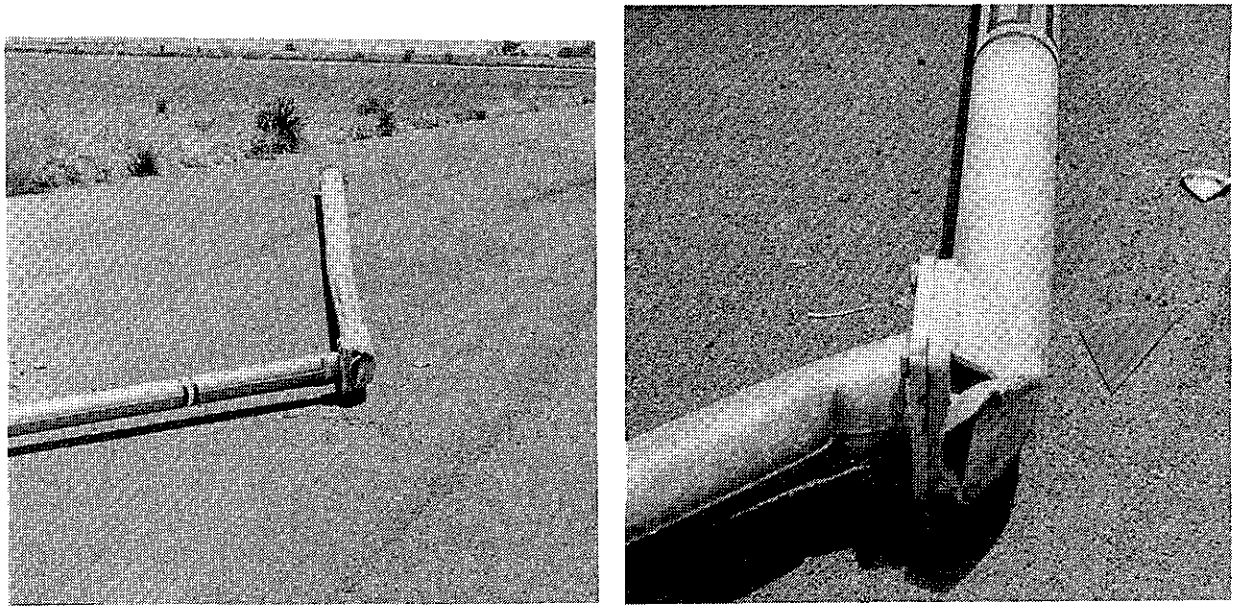
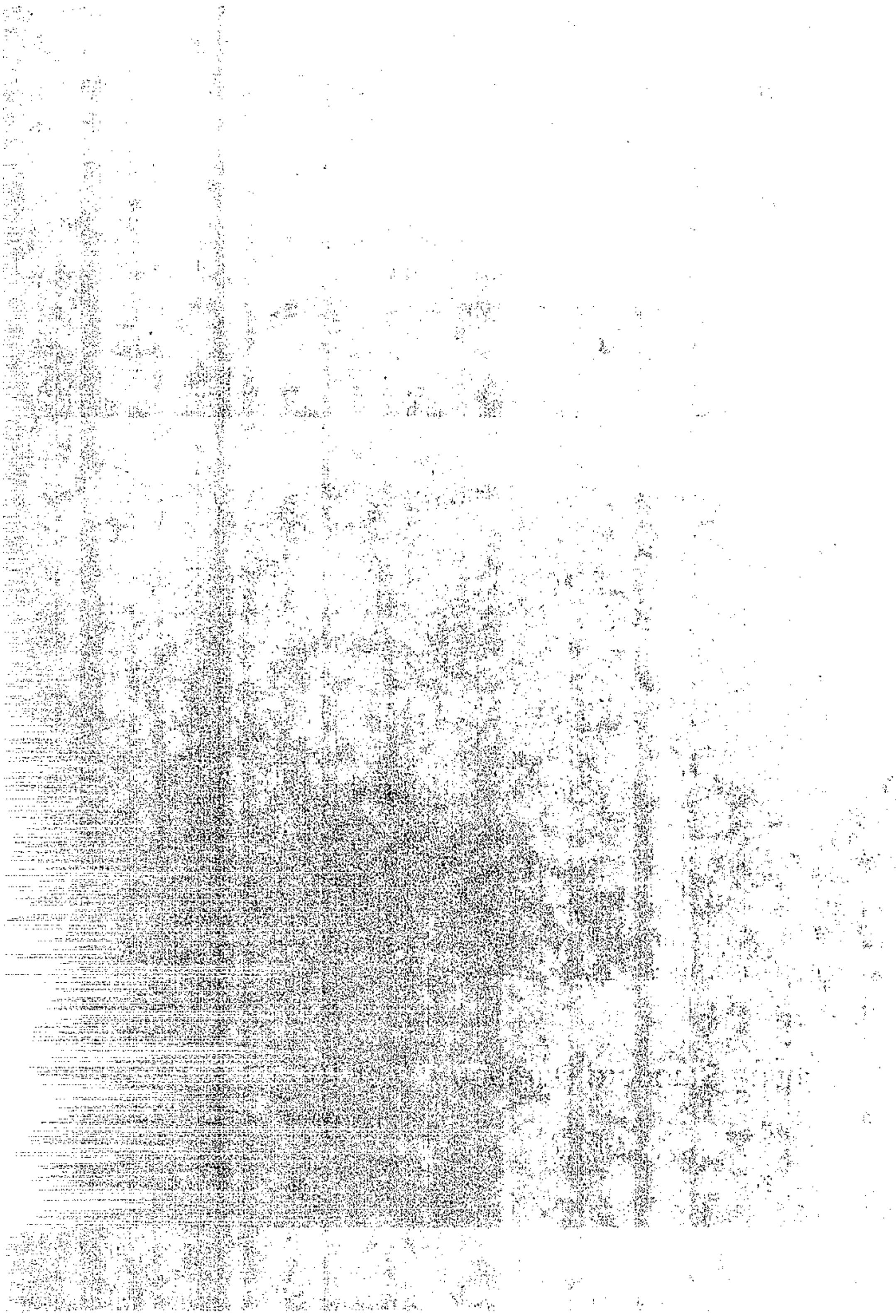


Figure 57. Lighting Standard Damage - Test 406



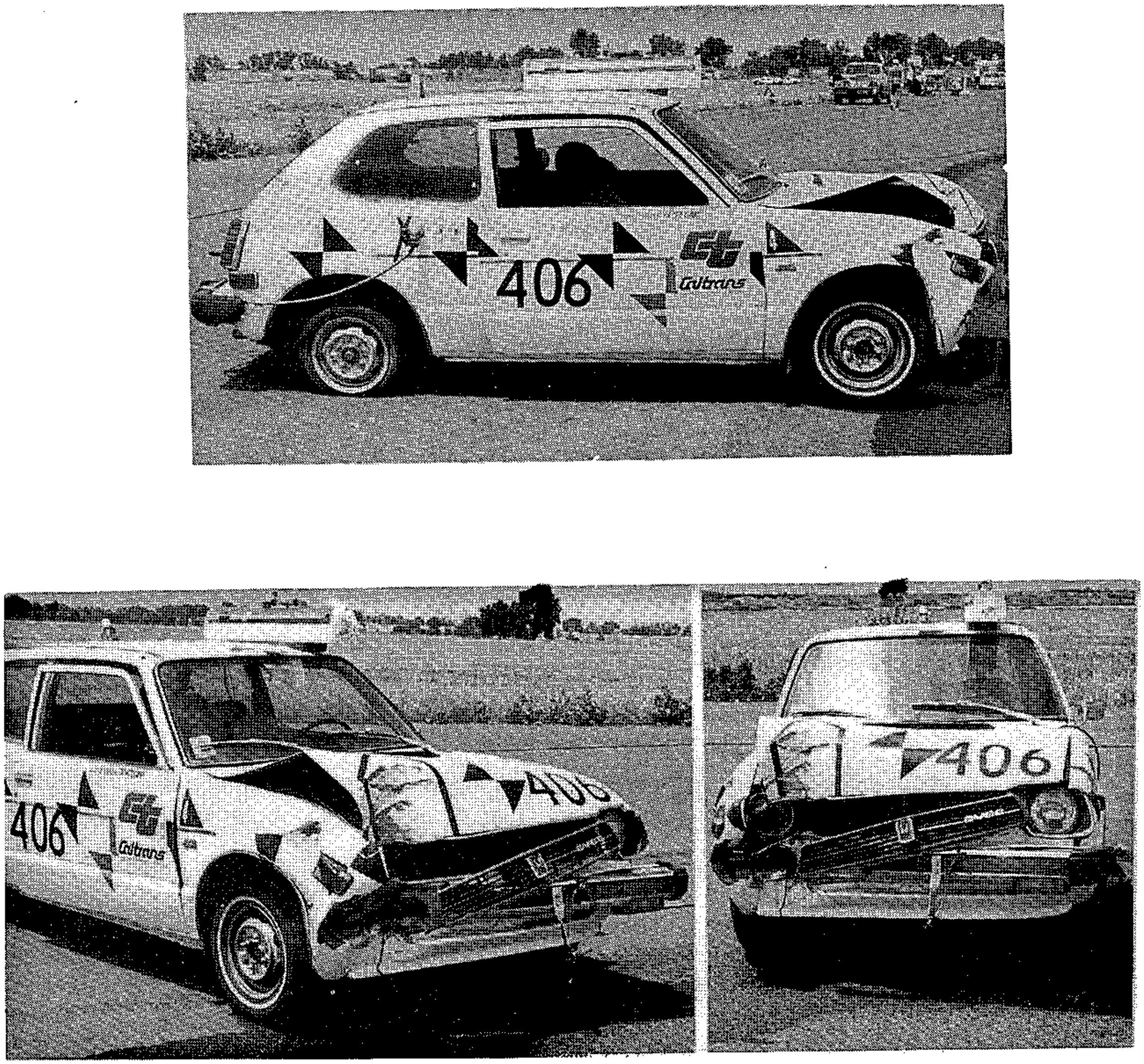


Figure 58. Test Vehicle After Impact - Test 406

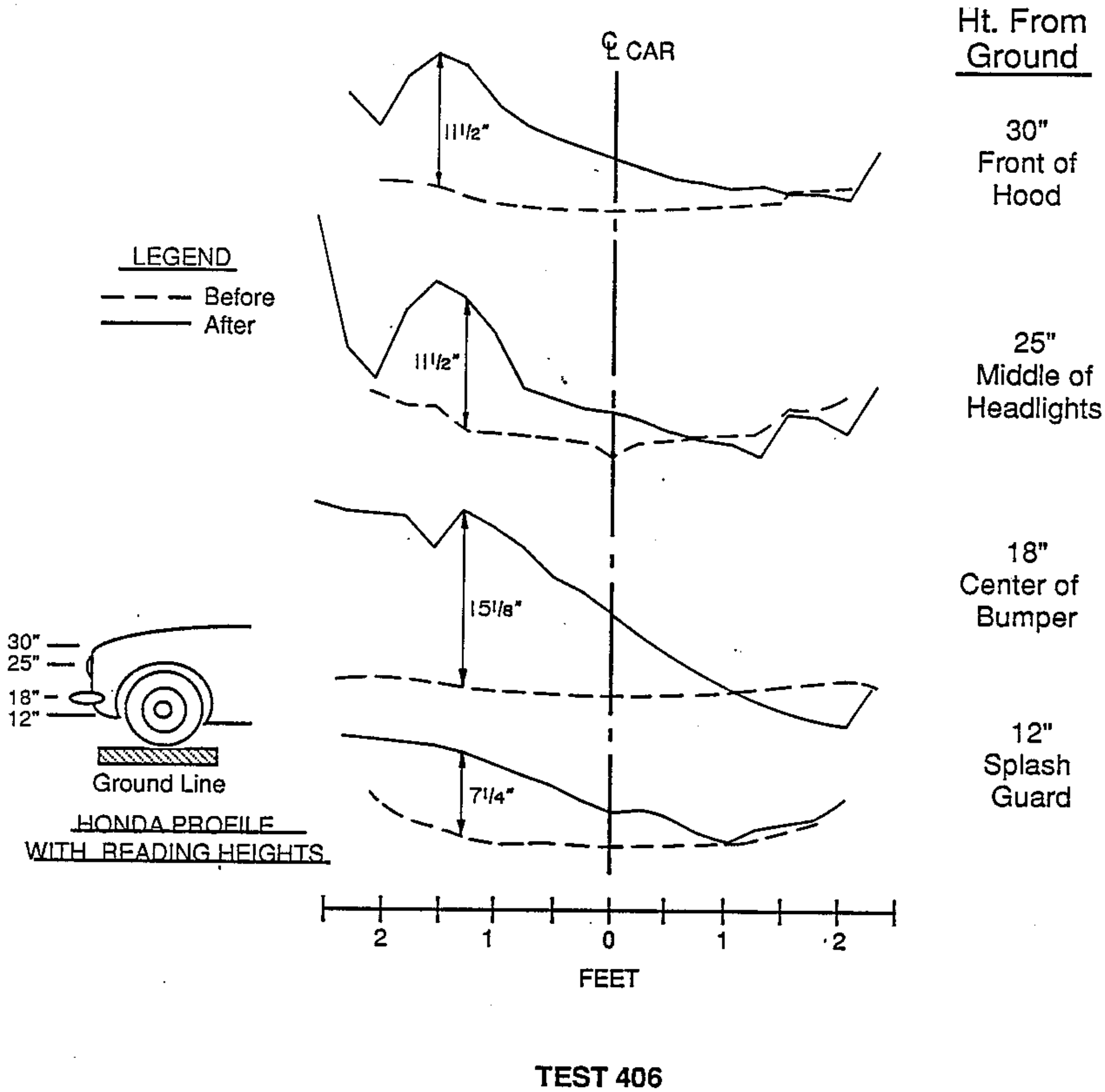
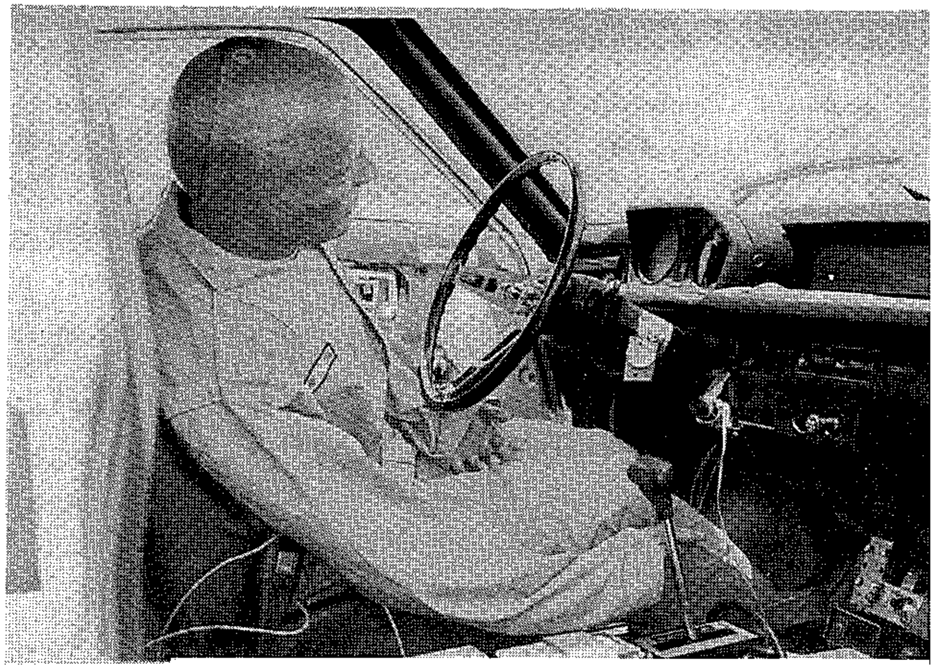


Figure 59. Crush Profiles of the Front End of Test Vehicle - Test 406



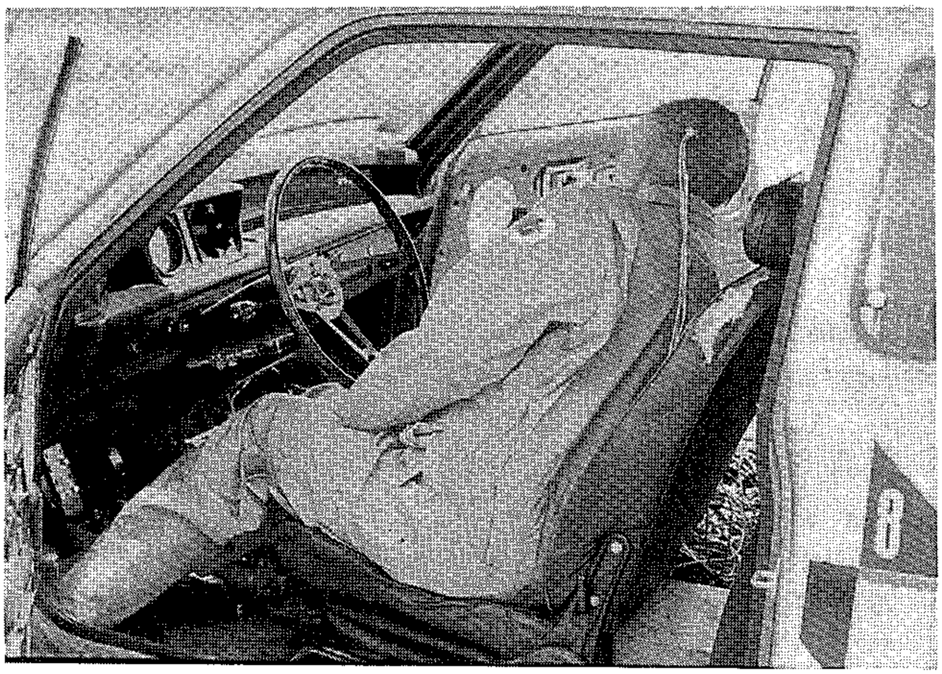


Figure 60. Dummy's Position After Impact - Test 406

5.2.7 Test 407 - Modified Type 31 Steel Lighting Standard with Standard Triangular Slip Base (1840-lb car/23.7 mph)

Test 407 was conducted according to procedures outlined for Test 62 of NCHRP Report 230, head-on at the center point of bumper at 20 mph using an 1800-lb car with a dummy placed in the driver's seat. The objective was to determine if a modified Caltrans type 31 steel lighting standard made from a thinner gage steel (as explained in section 5.1.2.1, 2, Figure 4) and equipped with a standard triangular slip base would meet all requirements of NCHRP Test 62. The summary of test data and photos taken before, during, and after the impact are shown in Figures 61. Accelerometer data plots are shown in Figures C25 to C28 in Appendix C.

5.2.7.1 Impact Description

The test vehicle impacted the base of the pole 3 in. to the right of the center of the front bumper. The impact speed was 23.7 mph, though the desired impact speed was 20 mph. Just after the test vehicle impacted the pole, the car pushed the pole base plate off the bottom slip base plate and gently pushed the pole in front of the front bumper. After impact, the pole base plate hooked under the front bumper and lifted the front end of the car slightly. The pole did not kick over the car, but rolled on the hood and roof of the car, and finally hooked and shattered the rear window. After impacting the pole, the vehicle decelerated without yaw while traveling southward in a straight line. The car finally came to a halt 120 ft downstream, due south of the foundation as shown in Figure 62.

5.2.7.2 Lighting Standard Damage and Trajectory

The surface of the pole where initial bumper impact occurred (18 in. from the ground to the center of the front bumper) was not dented or deformed. After impact, the pole base plate hooked under the front bumper. The pole was nudged ahead slowly by the car bumper and was not kicked up as in higher speed tests, but rolled on the hood and top of the car and, finally, hooked on rear window trim and shattered the window glass. The tip of the pole and the luminaire arm swung down and impacted the asphalt concrete pavement flattening the pole tip and cracking the end cap, Figure 63.

Figure 62 shows the schematic of the lighting standard damage and its final location. As shown, the base of the pole came to rest 43.8 ft south of the foundation. The tip of the mast arm came to rest approximately 18 ft due east of the foundation and was pointed due east, toward traffic lanes. The keeper plate landed 9 ft downstream (south) of the foundation with two of the three corners ripped open. No relative movement between the concrete foundation and the surrounding soil backfill was evident.

5.2.7.3 Luminaire Damage

The luminaire broke into pieces and remnants of the luminaire housing landed from 16 to 22 ft east of the foundation (shown in Figure 62)

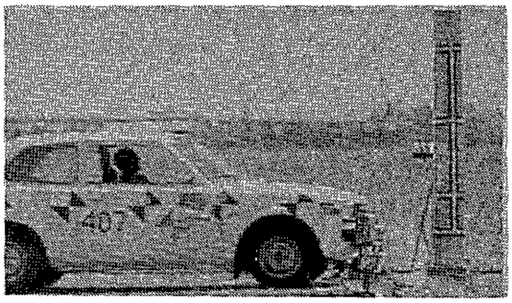
5.2.7.4 Vehicle Damage

Figure 64 show the test vehicle after the impact. The crush profiles of the front end of the vehicle (measured in horizontal planes at different heights) are shown in Figure 65. The maximum crush of the front bumper was 12-7/8 in.

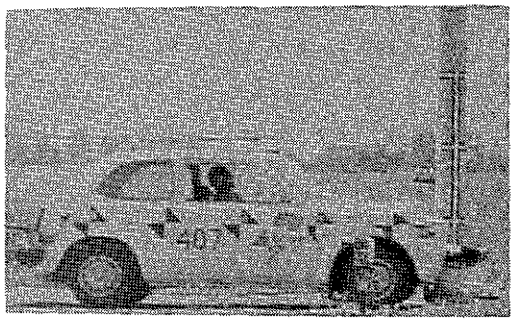
The windshield cracked, and the rear window shattered as the pole rolled on the hood and roof of the car. The radiator was crushed back to the fan, but the engine did not move. The front frame members under the engine were also bent. The vehicle could not be driven away after the impact; however, it could be rolled away. There was no intrusion of vehicle or lighting standard components into the passenger compartment due to the impact.

5.2.7.5 Dummy Behavior

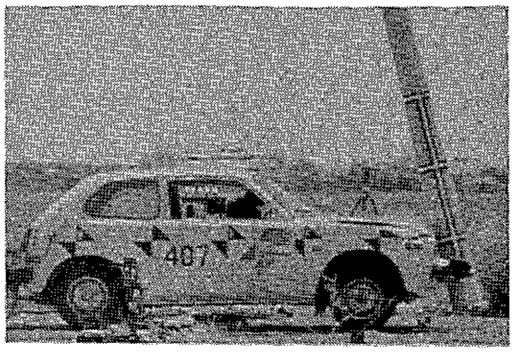
The test dummy, positioned in the driver's seat during the impact, was unrestrained. There was no internal camera coverage for the dummy due to a shortage of high-speed cameras. Upon impact, the dummy leaned forward slightly but did not hit the steering wheel. Figure 66 shows the dummy's position after the impact.



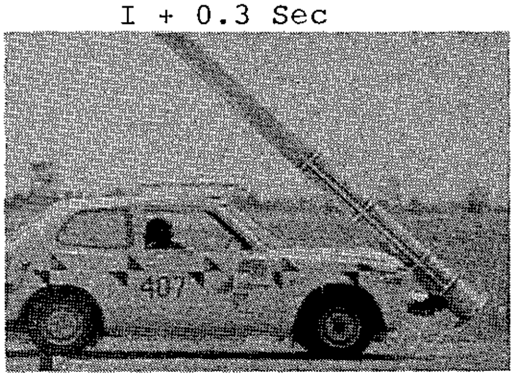
0.05 Sec Before Impact



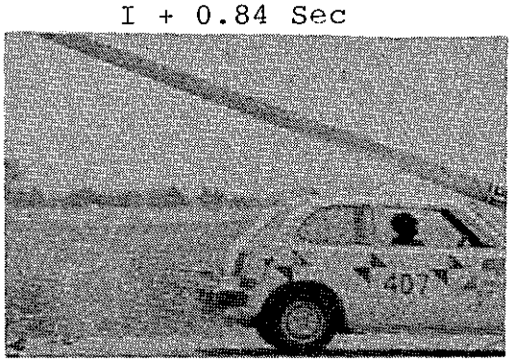
I + 0.03 Sec



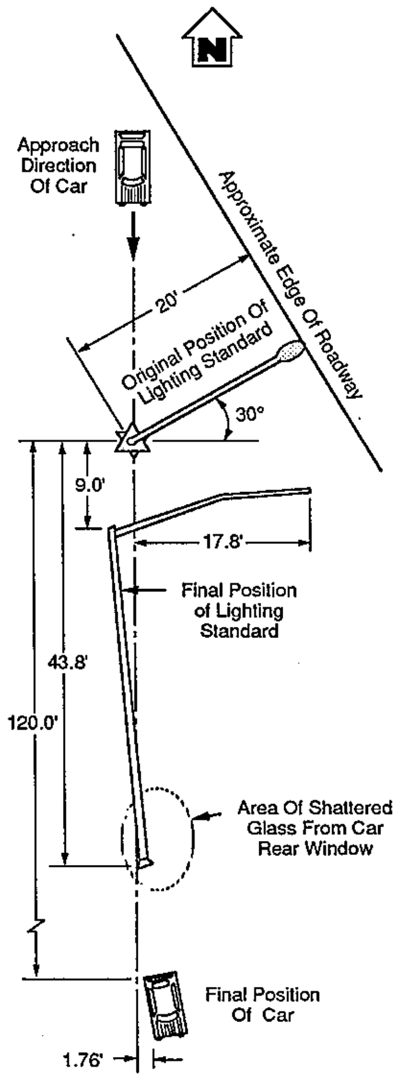
I + 0.3 Sec



I + 0.84 Sec



I + 1.12 Sec



VEHICLE	1979 Honda Civic
VEHICLE WEIGHT (Including dummy & instrumentation)	2005 Lb.
DUMMY RESTRAINT	None
IMPACT VELOCITY	23.7 Mph.
IMPACT LOCATION	3" Right of Centerline
OCCUPANT IMPACT VELOCITY LONG.	8.6 fps
VEHICLE DAMAGE (measured at bumper ht.)	12-7/8"
VEHICLE ACCELERATION (max. 50 msec avg.)	
LATERAL	-0.54 g's
LONGITUDINAL	-5.73 g's
VERTICAL	-1.63 g's
HEAD INJURY CRITERION	2

TEST NO.	407
DATE	June 23, 1987
TYPE OF LIGHT STD.	Modified Type 31
POLE MATERIAL	Galvanized Steel
POLE DIMENSIONS	33'-0" x 10" O.D. x 5-3/8" O.D.
THICKENED POLE BASE	2'-0" x 10" O.D. x 0.25"
MOUNTING HEIGHT	39'-3"
PROJECTED LENGTH OF MAST ARM	20'-0"
TOTAL WEIGHT	639.4 Lb.
BREAKAWAY DEVICE	Type 31 Triangular Slip base

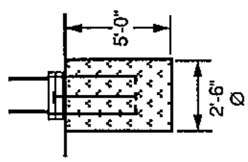


Figure 61. Test 407 Data Summary Sheet

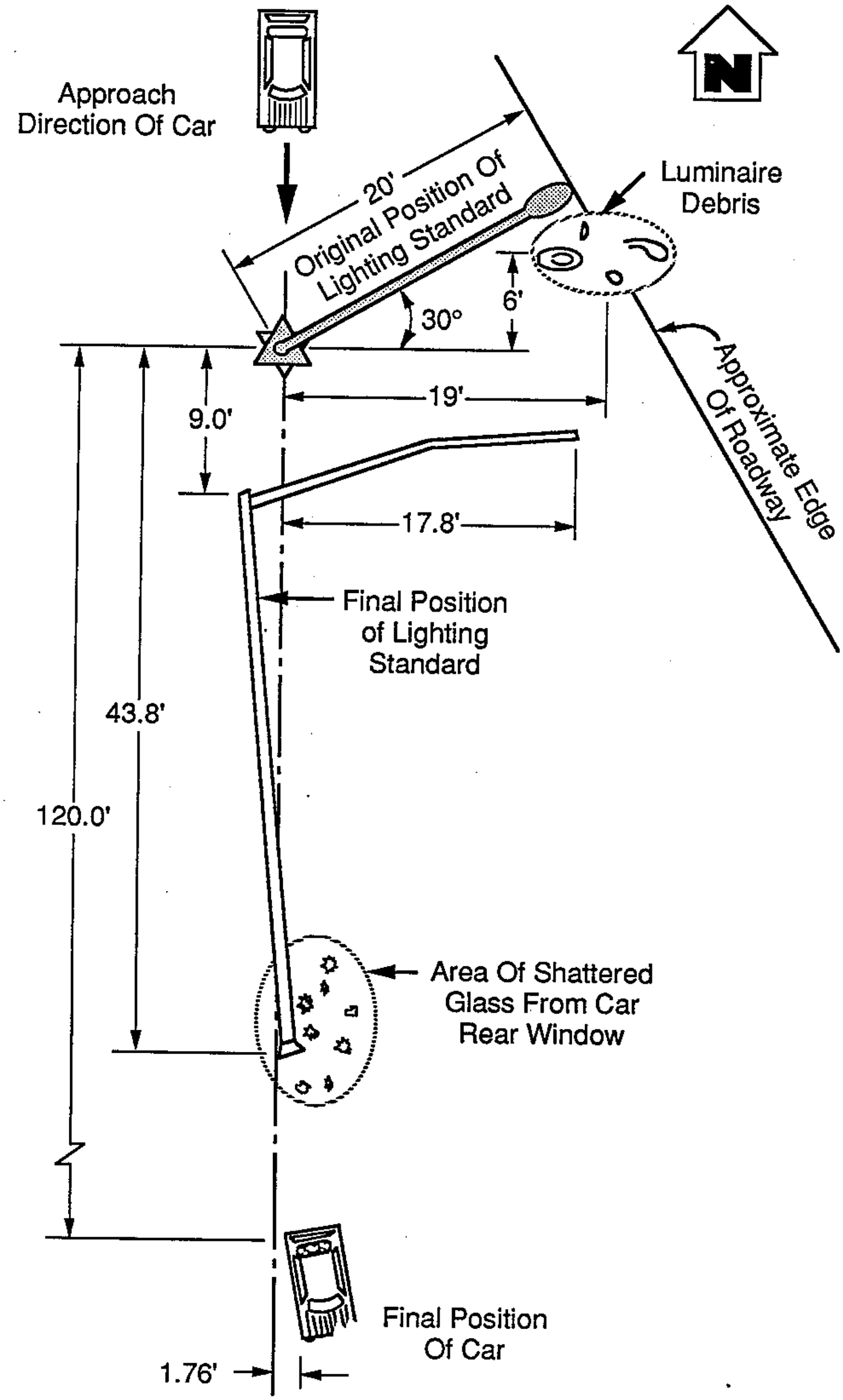
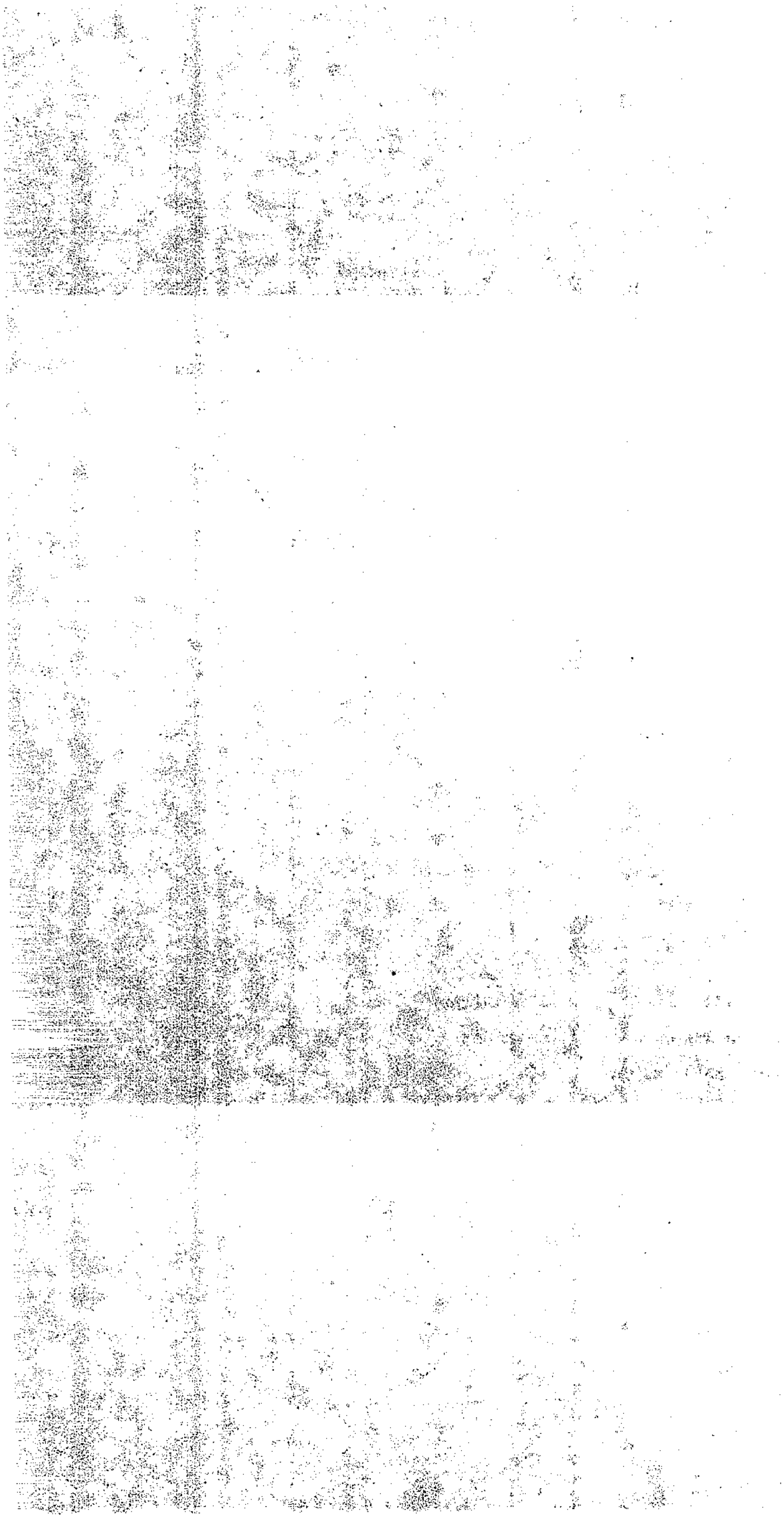
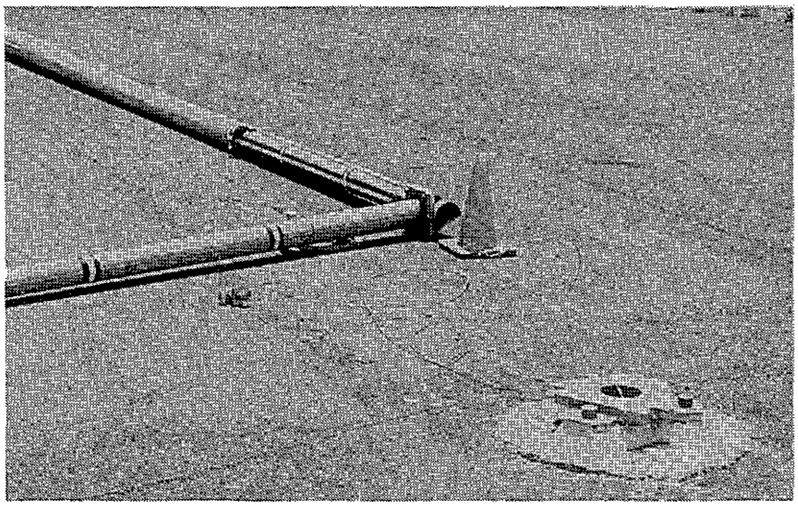


Figure 62. Final Location of the Lighting Standard and the Car After Collision - Test 407





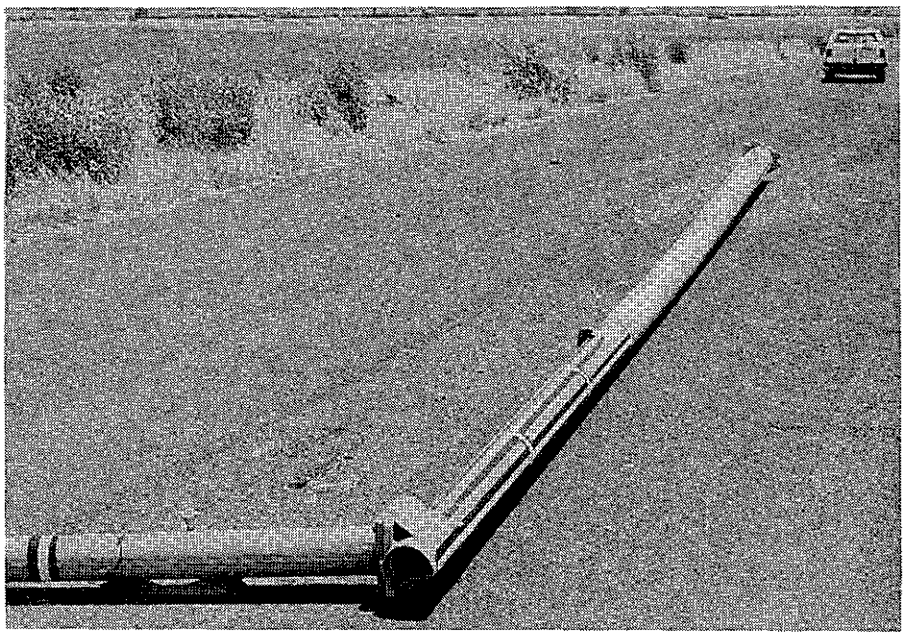
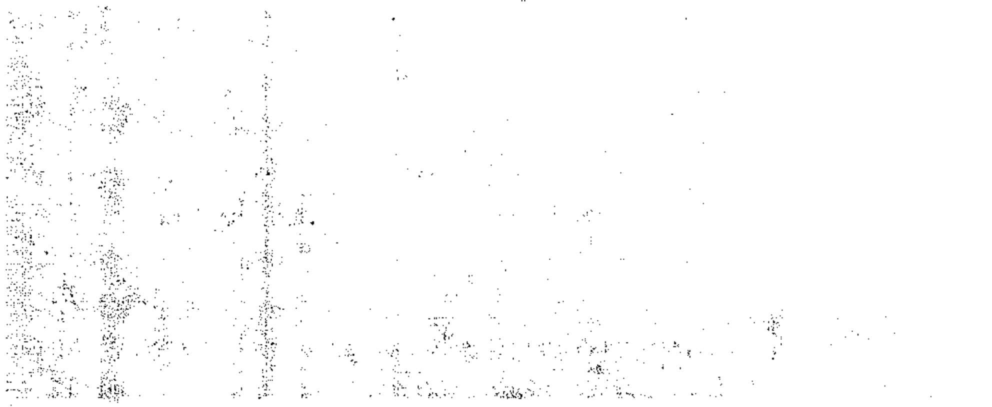
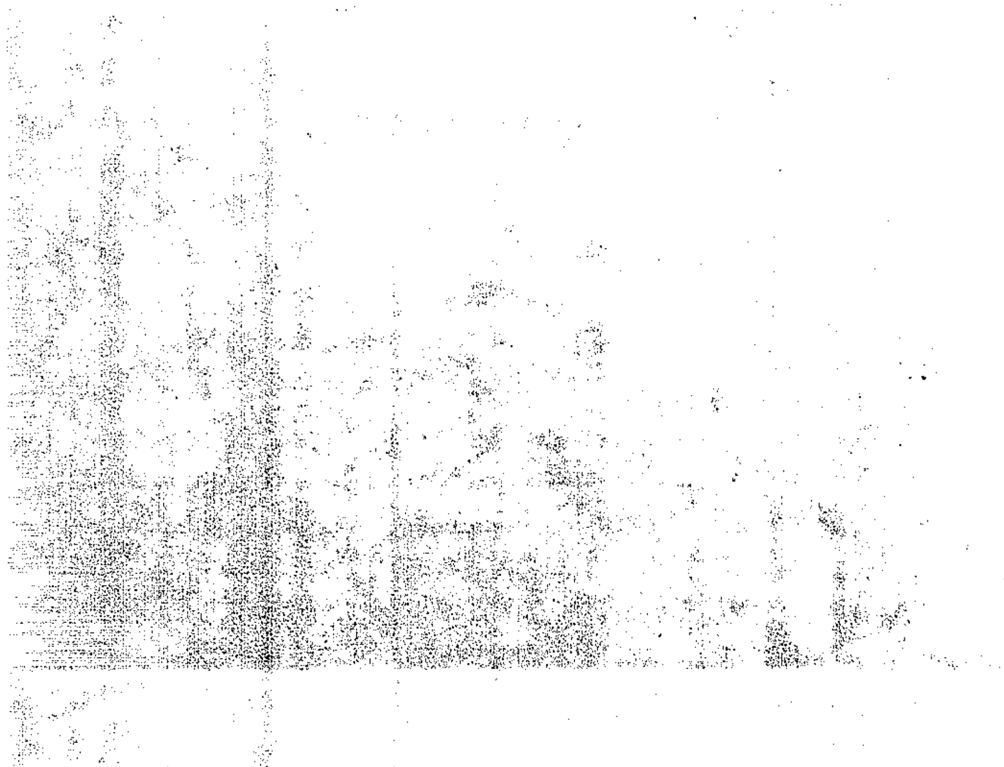


Figure 63. Lighting Standard Damage - Test 407

Figure 64. Test Vehicle After Impact - Test 407





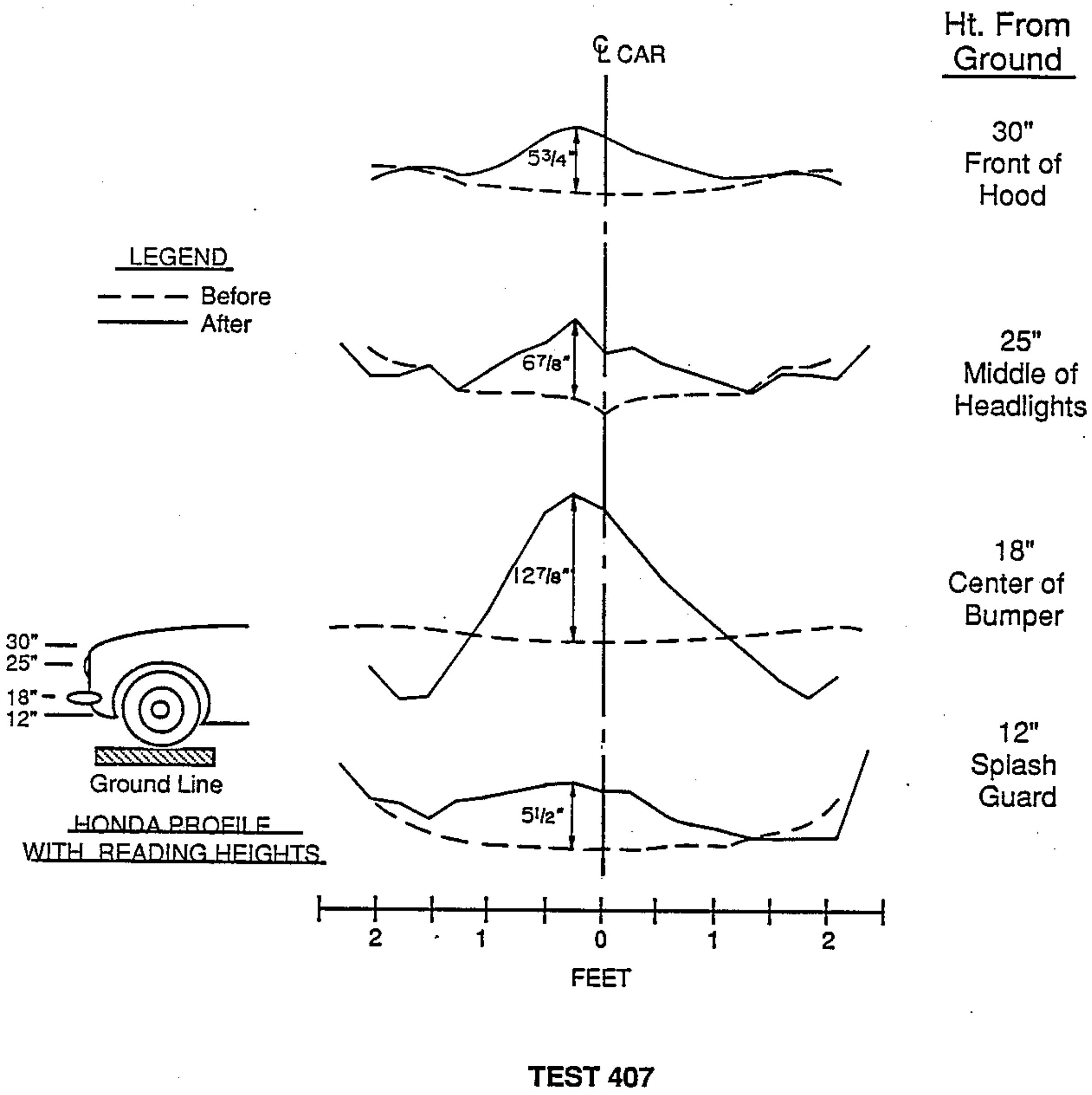


Figure 65. Crush Profiles of the Front End of Test Vehicle - Test 407

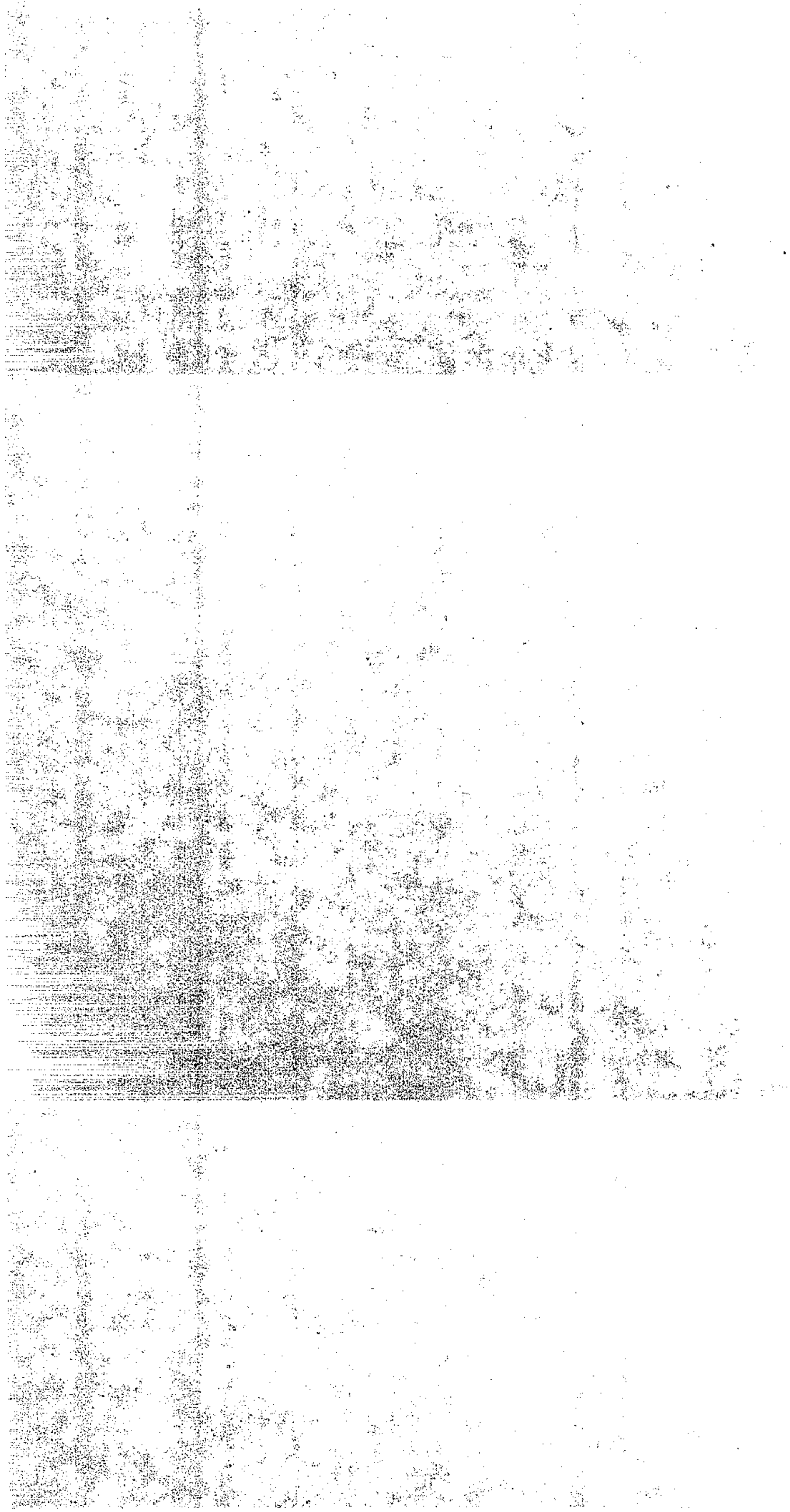


Figure 66. Dummy's Position After Impact - Test 407

5.2.8 X Rays and Static Tests of Aluminum Breakaway Couplings

5.2.8.1 X rays

The Transpo die-cast aluminum couplings were x rayed and then evaluated according to ASTM E505 category A reference radiographs (1). Verification x rays ordered by Caltrans were taken by Industrial Testing International, Inc. in Sacramento, California. A summary of results of Caltrans verification x rays is presented in the Table 2. Only couplings with a porosity defect level of 3 or better were considered acceptable.

Table 2. Summary of X Ray Evaluations of Transpo Die-Cast Aluminum Couplings

Date Tested	Lot No.	Number of Couplings	Porosity Defect Level
3-12-1983	3222	20	All rejectable per ASTM E505 Class 4
7-13-1983	3558	11	10 Class 2 ASTM E505 1 Class 4+ ASTM E505
2-16-1984	210	14	8 Class 3 ASTM E505 5 Class 4 ASTM E505 1 Class 2 ASTM E505

5.2.8.2 Static Tests

1 - Dimensional Checks

Dimensions of all ALCOA extruded aluminum couplings sent to Translab were measured. Table 3 shows the coupling dimensions as measured in Translab. The ALCOA model 100-1 couplings did not comply with Caltrans dimensional requirements as their

1-in.-diameter galvanized steel stud did not comply with the thread engagement length of 1-3/8 to 1-1/2 in. as required by Caltrans Standard Plans (23); the actual thread engagement length was 1 only in.

Table 3. Dimensions of ALCOA Extruded Aluminum Couplings

Item	Dimension (in.)	
	Caltrans Specifications	ALCOA Model 100-1
Coupling body:		
Total Length	4-3/4 to 4-7/8	4-3/4
Threaded Length	2-1/2 min.	2-7/8
Galv. Steel Stud:		
Top Stud Length	3 to 3-1/4	2-7/8
Embedment Length	1-3/8 to 1-1/2	1

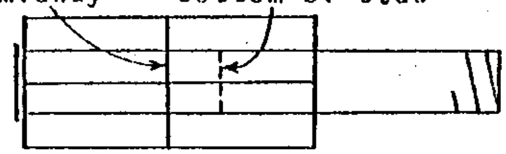
2 - Tensile Test

Three ALCOA model 100-1 extruded aluminum couplings were tested according to the procedure outlined in 5.1.6.2, 2. Each coupling tested in short-term tensile loading failed as designed when the top portion of the coupling body containing the short stud dilated and cracks initiated along the base of the fluted grooves. The stud then pulled out easily. The ultimate tensile loads obtained are shown in Table 4. As shown, the ultimate tensile loads were between 31,000 and 32,600 lb. Thus, all couplings tested exceeded the required 24,000-lb minimum tensile load as required by Caltrans specifications (Appendix E).

Eleven Transpo Industries die-cast aluminum couplings (from lots 3222, 3558, and 210) were also tested. Test results are

TABLE 4. RESULTS OF AXIAL TENSILE TESTS OF ALCOA EXTRUDED ALUMINUM COUPLINGS

Manufacturer: ALCOA
Test dates: Feb. 25 & 28, 1985
Machine: Baldwin Universal testing machine, 60,000 lb. capacity
Loading rate: 0.50 in./minute
Tested by Vu Bon, Walt Richards



Sample No.	Lot No.	Ultimate Load, lbs.	Comments	Location of failure
1-T	100-1*	31,000.		along grooves
3-T	100-1	32,000.		along grooves
4-T	100-1	32,600.		along grooves

* Manufactured in August 1984
** Manufactured in December 1983

summarized in Table 5. The results show that four of the five couplings from lot 210 failed to meet the minimum tensile load of 24000 lb (Appendix E), with two of the couplings, samples A9 and A7, having tensile strengths below 14,000 lb. These low tensile strengths were attributed to either fine, tight shrinkage cracks or a change in grain structure denoted by a dull gray color of the fractured surface near the center seam line of the coupling.

3 - Restrained Shear Tests

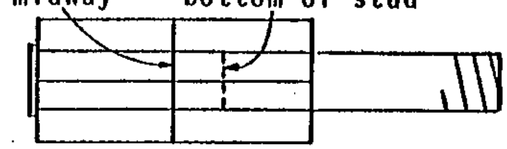
A total of 8 ALCOA model 100-1 couplings were tested in pairs to determine their ultimate restrained shear load according to the procedure outlined in section 5.1.6.2, 3. In each shear test the top coupling broke first and the bottom coupling broke later. Both couplings fractured in splitting shear at the coupling end where the top stud is located, and cracks were developed along the base of the flutes. All 1-in.-diameter ASTM A307 anchor bars used in the restrained shear tests were bent, with bending curvatures ranging between 3 and 8 degrees. Table 6 shows the summary of test results.

Fourteen Transpo Industries die-cast aluminum couplings (from lots 3222, 3558, and 210) were also tested in pairs for ultimate restrained shear. The results are shown in Table 7.

According to the Caltrans specifications for aluminum couplings (Appendix E), the restrained shear strength of an individual coupling shall be 3600 lb minimum and 5500 lb maximum. While the restrained shear strength of one of the ALCOA couplings was greater than 5500 lb maximum shear allowed, one of the Transpo couplings

TABLE 5. RESULTS OF AXIAL TENSILE TESTS OF TRANSPO DIE-CAST ALUMINUM COUPLINGS

Manufacturer: Transpo-Industries, Inc.
Test dates: Jan. 19 & March 1, 1984
Machine: Baldwin Universal testing machine, 60,000 lb. capacity
Loading rate: 0.50 in./minute
Tested by Vu Bon, Walt Richards

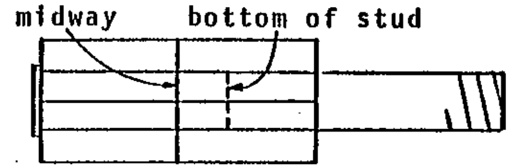


Sample No.	Lot No.	Porosity defect level per ASTM E505 (ITI Lab evaluation)	Ultimate Load, lbs.	Comments	Location of Failure
5	3222		Not a valid test	Fractured during set up	bottom of stud
2	3222	> 4	21,750	2 bubbles, 1/4"Ø	
6	3222	> 4	23,300	1 bubble, 1/4"Ø & many sm. bubbles	"
9	3222	> 4	26,000	2 bubbles, 1/4"Ø & many sm. bubbles	"
A8	210	4	21,500	1 bubble, 3/16"Ø & many sm. bubbles	"
A11	210	4	25,200	1 bubble, 3/16"Ø & many sm. bubbles	"
1	3558	2	25,940	1 bubble, 1/8"Ø & many sm. bubbles	"
2	3558	2	26,200	1 bubble, 1/8"Ø & many sm. bubbles	"
A1	210	3	21,600	very small bubbles	"
A7	210	3	13,600	gray grain structure possible shrinkage defect	midway
A9	210	3	8,750	gray grain structure possible shrinkage defect	"
10	3558	2	27,350	very small bubbles	"

Date received: lot 3222: 7-6-82
lot 3558: 7-12-83
lot 210: 2-14-84

TABLE 5. RESULTS OF AXIAL TENSILE TESTS OF TRANSPO DIE-CAST ALUMINUM COUPLINGS

Manufacturer: Transpo-Industries, Inc.
Test dates: Jan. 19 & March 1, 1984
Machine: Baldwin Universal testing machine, 60,000 lb. capacity
Loading rate: 0.50 in./minute
Tested by Vu Bon, Walt Richards



Sample No.	Lot No.	Porosity defect level per ASTM E505 (ITI Lab evaluation)	Ultimate Load, lbs.	Comments	Location of Failure
5	3222		Not a valid test	Fractured during set up	bottom of stud
2	3222	> 4	21,750	2 bubbles, 1/4"Ø	
6	3222	> 4	23,300	1 bubble, 1/4"Ø & many sm. bubbles	"
9	3222	> 4	26,000	2 bubbles, 1/4"Ø & many sm. bubbles	"
A8	210	4	21,500	1 bubble, 3/16"Ø & many sm. butbles	"
A11	210	4	25,200	1 bubble, 3/16"Ø & many sm. bubbles	"
1	3558	2	25,940	1 bubble, 1/8"Ø & many sm. bubbles	"
2	3558	2	26,200	1 bubble, 1/8"Ø & many sm. bubbles	"
A1	210	3	21,600	very small bubbles	"
A7	210	3	13,600	gray grain structure possible shrinkage defect	midway
A9	210	3	8,750	gray grain structure possible shrinkage defect	"
10	3558	2	27,350	very small bubbles	"

Date received: lot 3222: 7-6-82
lot 3558: 7-12-83
lot 210: 2-14-84

TABLE 6. RESULTS OF RESTRAINED SHEAR TESTS OF ALCOA EXTRUDED ALUMINUM COUPLINGS

Manufacturer: ALCOA
Test dates: Feb. 26, 28 and March 4, 1985
Testing machine: Baldwin Universal testing machine, 60,000 lb. capacity
Loading rate: 0.5 in./minute
Tested by Vu Bon, Walt Richards

Sample No.	Lot No.	Type of nut	Applied torque	Recorded load, lbs.	Mean shear per coupling, lbs.	Degree of bend of anchor rod	Comments	Location of fracture
1S-T	100-1	HEX	175.	11,600.	5,800.	6°	fractured first	along groove
1S-B	100-1	HEX	175.			8		"
2S-T	100-1	ALCOA	170.				Invalid test*	
2S-B	100-1	ALCOA	165.					
4S-T	100-1	ALCOA	160.	10,550.	5,275.	3		along groove
4S-B	100-1	ALCOA	175.			4		"
5S-T	100-1	ALCOA	180.	11,000.	5,500	7		along groove
5S-B	100-1	ALCOA	190.			8		"

* inappropriate loading rate.

TABLE 7. RESULTS OF RESTRAINED SHEAR TESTS OF TRANSPO DIE-CAST ALUMINUM COUPLINGS

Manufacturer: Transpo-Industries Inc.
Test dates: Jan. 24 & March 1, 1984
Testing machine: Baldwin Universal testing machine, 60,000 lb. capacity
Loading rate: 0.5 in./minute
Tested by Vu Bon, Walt Richards

Sample No.	Lot No.	Porosity defect level per ASTM E505	Recorded load, lbs.	Mean shear per coupling, lbs.	Comments	Location of fracture
4	3222	>4	9,630	4,815	1/4"Ø bubble	bottom of stud
10	3222	>4		"	1/4"Ø bubble	"
3	3222	>4	7,200	3,600	2 bubbles, 1/4"Ø	"
8	3558	>4		"	1/4"Ø bubble	"
A4	210	4	5,920	2,960	small bubbles	"
A5	210	4		"		did not fail
11	3222	>4	8,130	4,065	1/4"Ø bubble	bottom of stud
12	3222	>4		"	small bubbles	"
6	3558	2	7,880	3,940	1/8"Ø bubble	"
7	3558	2		"		did not fail
4	3558	2	9,000	4,500	small bubbles	bottom of stud
16	3222	3		"	small bubbles	"
A2	210	3	10,900	5,450	3/16"Ø bubble	"
A3	210	3		"	3/16"Ø bubble	"

had restrained shear strength of 2965 lb, well below the 3600-lb minimum allowed.

4 - Fatigue Tests

Three model 100-1 ALCOA couplings were tested under a cyclic load ranging from +6.5 to +12 kips according to the procedure outlined in 5.1.6.2-4.

The first coupling, sample 1F, did not fracture when subjected to over 2 million cycles (+6.5 to 12 kips). The second and third couplings (samples 2F and 3F); however, fractured along the top of the studs at 1,986,600 and 717,900 cycles respectively. Table 8 shows the summary of test results.

Fatigue tests were also conducted on Transpo die-cast aluminum breakaway couplings. The summary of test results is given in Table 9. There were no coupling failures, and all couplings exceeded 2 million cycles of loading, except sample No. 13 which was subjected to a load range of +9 to 16.8 kips. This coupling failed after 98,900 cycles.

TABLE 8. RESULTS OF FATIGUE TESTS ON ALCOA EXTRUDED ALUMINUM COUPLINGS

Manufacturer: ALCOA
Test dates: from 2-21 to 3-7-85
Testing machine: MTS electro hydraulic, 75k capacity
Loading rate: 10 hertz
Tested by Vu Bon, John Dusel, and Walt Richards

Test Date	Sample No.	Lot No.	Porosity defect level ITI	Load Range kips	No. of cycles to failure	Comments	Ult tensile load, kips	Location of fracture
2-21-85 to 2-25-85	1F	100-1		+6.5 to +12	exceeded 2 x 10^6 did not fail	Using ALCOA nut	25.8	bottom of stud
2-25-85 to 3-01-85	2F	100-1		+6.5 to +12	1,986,600.	Using HEX nut		bottom of stud
3-01-85 to 3-04-85	3F	100-1		+6.5 to +12	717,900.	Using ALCOA nut		bottom of stud

Cyclic frequency: 10hz
Sinusodial loading pattern

TABLE 9. RESULTS OF FATIGUE TESTS ON TRANSPO DIE-CAST ALUMINUM COUPLINGS

Manufacturer: Transpo-Industries Inc.
Test dates: Feb. 16 to March 4, 1984
Testing machine: MTS electro hydraulic, 75k capacity
Loading rate: 10 hertz
Tested by Vu Bon, John Dusel, and Walt Richards

Test Date	Sample No.	Lot No.	Porosity defect level ITI	Load Range kips	No. of cycles to failure	Comments	Ult tensile load, kips	Location of fracture
2-17-84 to 2-18-84	13	3222	3	+9to+16.8	98,900	gray grain structure poss. shrink. defect	--	midway
2-21-84 to 2-24-84	14	3222	3	+6.5to+12	exceeded $2x10^6$ did not fail	small bubbles	22.46	bottom of stud
2-24-84 to 2-27-84	A6	210	3	+6.5to+12	"	small bubbles	23.02	"
2-27-84 to 3-1-84	1	3222	>4	+6.5to+12	"	1/4"Ø bubble	21.60	"
3-1-84 to 3-5-84	A12	210	4	+6.5to+12	"	many 1/8"Ø bubbles w/ gray grain structure	25.41	midway
11-22-82 to 11-29-84	8	3222	>4	-2.0to+7.5	"	--	--	--
11-29-82 to 12-9-84	7	3222	>4	-2.0to+7.5	"	--	--	--

Cyclic frequency: 10hz - except samples #7 and #8 at 3hz -
Sinusodial loading pattern

5 - Corrosion Tests

Three model 100-1 ALCOA couplings and one Transpo coupling were tested according to the procedure outlined in section 5.1.6.2, 5. A summary of test results is presented in the following Table.

Table 10. Summary of Corrosion Tests of Aluminum Couplings

Observation	Stainless Steel Stud W/galv. hex nut			Galv. Steel Stud W/galv. hex nut			Galv. Steel Stud W/Alum. nut		
	Stud	Nut	Washer	Stud	Nut	Washer	Stud	Nut	Washer
Overall Observation	A	B	C	C	C	C	C	A	C
Sawn Stud, Nut, Washer	A	A	A	A	A	A	A	A	A

Note: A: None or very little corrosion.
B: Mildly corroded - zinc metal mostly gone:
C: Moderately corroded.
D: Badly corroded

5.3 Discussion of Test Results

5.3.1 General - Safety Evaluation Guidelines - NCHRP Report 230

National Cooperative Highway Research Program (NCHRP) Report No. 230, "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances" (19) recommends three appraisal factors for evaluating the crash test performance as follows:

1 - Structural Adequacy
2 - Occupant Risk
3 - Vehicle After-Collision Trajectory

The crash test results will be evaluated based on these criteria as outlined in Report 230. The results will also be compared with the 1985 AASHTO specifications.

In addition, test results will be compared with reference to Tests 404 and 405 which were conducted using the Caltrans type 31 lighting standards and were considered as control tests. Finally, the results will be compared to those obtained by FHWA. Table D1 is the summary of crash test results (done by Caltrans and other agencies) on lighting standards with standard triangular slip base or aluminum couplings.

The results of specification compliance tests (x rays and static tests) performed on both, the die-cast aluminum couplings manufactured by Transpo Industries, and the extruded aluminum couplings made by ALCOA (Aluminum Company of America) will be compared with the Caltrans specifications (Appendix E).

5.3.1.1 Structural Adequacy

In Table 6 of NCHRP Report 230 (19), the structural adequacy evaluation criterion for breakaway or yielding supports is defined as follows:

"B. The test article shall readily activate in a predictable manner by breaking away or yielding."

"D. Detached elements, fragments or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic."

The structural adequacy of breakaway lighting standards used in this study are evaluated based on the above criteria as follows:

1- In Tests 401 (58.6 mph) and 402 (19.6 mph) where aluminum lighting standards with aluminum breakaway couplings were used, the breakaway device sheared off as expected. There was no significant damage to the passenger compartment; however, in Test 402 the test vehicle's windshield cracked and the roof was dented 1.25 in. as the pole contacted the roof after the impact. This did not appear to have posed a great danger to the hypothetical occupants of the car. In Test 402 the lighting standard final position projected 5.9

ft into the outside traffic lane and the debris from luminaire breaking also landed in the outside traffic lanes. This would probably have caused little or no damage to traffic in the outside lane. Although in Test 402 part "D" was not strictly satisfied, Tests 401 and 402 were considered to have satisfied the structural adequacy criteria.

2- In Test 403 (59.1 mph) where a lightweight steel lighting standard (modified type 31) equipped with Transpo die-cast aluminum breakaway couplings was used, the breakaway couplings sheared off upon impact and there was no damage to the vehicle's passenger compartment. The lighting standard final position and debris from luminaire breaking were also outside traffic lanes; however, one piece of the luminaire's cast aluminum cover landed in the traffic lane. Since this piece was small, it would probably have caused little or no damage to oncoming traffic. Thus, Test 403 satisfied the structural adequacy criteria.

3- In Tests 404 (19.9 mph) and 405 (53.9 mph) which were conducted using the Caltrans type 31 steel lighting standard with the standard triangular slip base, the triangular slip base broke away as designed, and there was only a little damage to the passenger compartment in Test 404 as the pole slid off the rear quarter panel of the vehicle. In Test 404 the tip of the mast arm projected about 1 ft in the outside traffic lane and debris from luminaire breaking fell in the traffic lanes in both tests. This could have caused some damage to the traffic in the outside lane. Thus, except for the lighting standard trajectory, all other criteria for structural adequacy were satisfied in Tests 404 and 405. Although in Test 405 the speed was 53.9 mph (60 mph desired), it can be judged that a 60 mph test would also pass the structural adequacy criteria.

4- In Tests 406 (58.8 mph) and 407 (23.7 mph) where lightweight steel lighting standard (similar to the one used in Test 403) were used , the breakaway device, the standard triangular slip base, broke away as expected. There was also no significant damage to the passenger compartment; however, in Test 407 (slow test, 20 mph) the roof of the car was dented, windshield cracked, and the rear window was shattered as the pole rolled on the vehicle's roof. This did not appear to have posed a great danger to the hypothetical occupants of the car. Shattering of rear window may occur over a range of low impact speeds somewhere between 20 and 40 mph, no matter how effective the breakaway device, because of the pole low trajectory. The lighting standard final position was outside traffic lanes in both tests; however, debris from luminaire breaking landed in traffic lanes in Test 407. This could have caused some damage to the traffic in the outside land. Thus, except for some minor exceptions (part "D" was not strictly satisfied in Test 407), Tests 406 and 407 were considered to satisfy all other criteria for structural adequacy.

In summary, none of the tests completely satisfied the structural adequacy criterion. Either there was some damage, slight though it was, to the passenger compartment from the falling pole, or lighting standard and luminaire debris created a potential hazard to traffic in the outside lane. However, since NCHRP Report 230 does not clearly define what passenger compartment intrusion is or what constitutes undue hazard to other traffic, it was judged that in all seven tests no significant damage to the passengers or to nearby traffic was likely to occur. Thus, all seven tests were considered to have satisfied the structural adequacy criteria.

5.3.1.2 Occupant Risk

The occupant risk (as defined in NCHRP Report 230) relates to the degree of hazard to which occupants in the impacting vehicle would be subjected and is measured in terms of the velocity a hypothetical unrestrained occupant strikes the instrument panel or door and the subsequent occupant ridedown accelerations.

In Table 6 of NCHRP Report 230 (19) the occupant risk evaluation criterion for breakaway or yielding supports is defined as:

"E. The vehicle shall remain upright during and after collision, though moderate roll, pitching and yawing are acceptable. Integrity of the passenger compartment must be maintained with essentially no deformation or intrusion."

"F. Impact velocity of hypothetical front seat passenger against vehicle interior, calculated from vehicle accelerations and 24. in (0.61m) forward and 12 in (0.30m) lateral displacements, shall be less than:

Occupant Impact Velocity-fps	
Longitudinal	Lateral
40/F1	30/F2

and the vehicle highest 10 ms average accelerations subsequent to instant of hypothetical passenger impact should be less than:

Occupant Ridedown Accelerations-g's	
longitudinal	Lateral
20/F3	20/F4

Where F1, F2, F3, and F4 are appropriate acceptance factors."

Since all tests were head-on, only the longitudinal velocities and accelerations were critical. The suggested values for the acceptance factors F1, and F3 in Table 8, Chapter 4 of Report 230 are 2.67 and 1.33 respectively resulting in maximum values of 15 ft/sec (occupant impact velocity), and 15 g's (occupant ridedown acc.).

"G. (Supplementary) Anthropometric dummy responses should be less than those specified by FMVSS 208, i.e., resultant chest acceleration of 60g, Head Injury Criterion of 1000, and femur force of 2250 lb (10 kN) and by FMVSS 214, i.e., resultant chest acceleration of 60g, Head Injury Criterion of 1000, and occupant lateral impact velocity of 30 fps (9.1 m/s)."

Report 230 states that "the occupant risk criteria should be considered as the guidelines for generally acceptable performance. These criteria are not valid; however, for use in predicting occupant injury in real or hypothetical accidents."

The occupant risk evaluation of the breakaway lighting standards tested based on the above criteria are as follows:

1- In Tests 401 and 402 (aluminum lighting standards with aluminum breakaway couplings) the test vehicle remained upright during and after the impact with no significant yaw. There was also no significant damage to the passenger compartment; however, in Test 402 (19.6 mph) the test vehicle's windshield cracked and the roof was dented 1.25 in. as the pole contacted the roof after the impact. This did not appear to have posed a great danger to the hypothetical occupants of the car. Thus, Tests 401 and 402 satisfied the first part (E) of the occupant risk criteria.

The second part, criterion F, calls for an occupant impact velocity of less than 15 fps (calculated as stated in part "F" of the occupant risk criteria) and a highest 10 ms average value of longitudinal acceleration of 15 g's subsequent to instant of hypothetical passenger impact (Occupant Ridedown Acceleration).

The occupant impact velocity and the Dummy's Head Injury Criteria (HIC) in Tests 401 and 402 were calculated and are summarized in Figures 22 and 30. These values are well below the maximum occupant impact velocity of 15. fps and the maximum HIC of

1000 as specified in report 230.

The ridedown acceleration was not calculated; however, by inspection, it was much less than 15 g's for all seven tests. The maximum 50 ms average acceleration values were calculated and are well below 15g's for all tests. NCHRP Report 230 calls for a 10 ms average acceleration, however, the data reduction software was only capable of calculating the 50 ms average acceleration as specified in TRC 191.

2- In Test 403 (lightweight steel lighting standard equipped with Transpo die-cast aluminum breakaway couplings) the vehicle remained upright with no significant yaw or damage to the passenger compartment. The values of occupant impact velocity and the HIC were less than those of NCHRP Report 230.

3- In Tests 404 and 405 (Caltrans type 31 steel lighting standard with the standard triangular slip base) the test vehicle remained upright during and after the impact with no significant yaw; however, in Test 405 (off-center impact) the vehicle yawed immediately after the impact, and then followed a straight path. There was also no significant damage to the passenger compartment; however, a little damage was done to the passenger compartment in Test 404 as the pole slid off the rear quarter panel of the vehicle. The occupant impact velocity and the HIC values were below those of NCHRP Report 230.

4- In Tests 406 and 407 (lightweight steel lighting standard with triangular slip base, modified type 31), the test vehicle remained upright; however, in Test 406 the vehicle had a substantial yaw just after the impact but the car seemed to straighten out after a short distance. There was also no significant damage to the passenger compartment; however, in Test 407, the car's roof was dented, the windshield cracked, and the rear window shattered. As mentioned before, this did not appear to have posed a great danger to the hypothetical occupants of the car. The values of occupant impact velocity and the HIC were below those of NCHRP Report 230.

Thus, except for some minor passenger compartment intrusion (Tests 402, 404, and 407), all seven tests (401 to 407) satisfied the Occupant Risk Criteria.

5.3.1.3 Vehicle After-Collision Trajectory

Vehicle trajectory hazard (as defined in NCHRP Report 230) is a measure of the potential of after-collision trajectory of the vehicle to cause a subsequent multivehicle collision or subject vehicle occupants to undue hazard. The commentary states, "For breakaway or yielding supports, the trajectory of a vehicle after it has collided with a test article that satisfies structural adequacy and occupant risk requirements is generally away from the traffic stream and, hence, is normally noncritical."

In Table 6 of NCHRP Report 230 (19) the vehicle after-collision trajectory evaluation criterion for breakaway or yielding supports is defined as follows:

"H. After collision, the vehicle trajectory and final stopping position shall intrude a minimum distance, if at all, into adjacent traffic lanes."

"J. Vehicle trajectory behind the test article is acceptable."

All seven crash tests (401 to 407) satisfied the vehicle trajectory criteria. In all 20 mph crash tests (402, 404, 407), the vehicle was stopped after travelling straight ahead for a short distance. In the 60 mph tests (401, 403, 405, 406), though in some tests the vehicle yawed just after the impact, it continued straight ahead until it was braked remotely.

5.3.2 Comparison with 1985 AASHTO Specifications

The 1975 AASHTO specifications for breakaway supports (AASHTO Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals) was revised in 1985. In the new specifications the weight of the crash test vehicle has been lowered from 2250 to 1800 lb, and the change in momentum acceptance criteria (1100 lb-sec, preferably 750 lb-sec momentum change for 2250-lb cars) has been changed by change in velocity criterion of 15 fps and preferably 10 fps. Also a 4 in. stub height clearance has been added to reduce the likelihood of vehicle undercarriage snagging.

Change in velocities for all tests (401 to 407) were below the 15 fps (ranging from 8.54 to 13.1 fps) specified by 1985 AASHTO, and the stub heights in Tests 401, 402, and 403 where aluminum couplings were used were about 3.5 in. In Tests 404, 405, 406, and

407 where triangular slip bases were used the stub height was 4.5 in. (4.5 in. was the maximum allowed by the 1984 Caltrans Standard Plans, see Figure 6); however, no vehicle undercarriage snagging was observed. Thus all tests essentially satisfied the 1985 AASHTO specifications. The 1988 Caltrans Standard Plans have been modified to reflect new revisions, and the maximum height for the lower slip base plate has been lowered to 4 in.

5.3.3 Comparison with tests by FHWA

During 1981-1982 ENSCO conducted similar crash tests on a 1003-lb steel surrogate lighting standard without mast arm and with a triangular slip base (similar to Caltrans type 31). Results of ENSCO's Tests 1469-2A82, and 1469-3A82 are given in Table D1.

Results of ENSCO Test 1469-2A82 (60 mph, off-center) satisfied the structural adequacy criterion; however, the occupant risk and the vehicle trajectory following the impact did not meet the requirements of NCHRP Report 230 because of substantial yaw and rollover of the test vehicle after the impact. In ENSCO Test 1469-2A83 (20 mph, off-center), the structural adequacy and the vehicle after collision trajectory criteria of NCHRP Report 230 were met; however, the occupant risk criterion was not satisfied as the change in velocity was 19.3 fps. This exceeds the maximum of 15 fps specified in NCHRP Report 230.

During 1984-1985, ENSCO conducted a series of crash tests using the 1800-lb FOIL reusable bogie. The bogie simulated a 1977 VW Rabbit. Test results for steel poles (1003-lb surrogate and 292-lb small pole) on triangular slip base and 282-lb aluminum pole on

ALCOA type 100 couplings are given in Table D1, Appendix D.

ENSCO Test 501 was conducted using a 1003-lb steel surrogate lighting standard on type 31 triangular slip base. This test did not satisfy the occupant risk criteria as the change in velocity was 16.1 fps. ENSCO Tests 504, 509, and 515 were conducted using a 292-lb small (28-ft-high) steel pole on type 31 triangular slip base. All the criteria of NCHRP Report 230 were met. Tests 502, 505, and 508 were conducted using a 282-lb aluminum pole on ALCOA aluminum coupling. All criteria of NCHRP Report 230 were met, except in ENSCO Test 505, the occupant risk criteria was not satisfied as the change in velocity was 19.6 fps.

In 1987, Analysis Group Inc. (AGI) performed a series of crash tests for FHWA at the Federal Outdoor Impact Laboratory (10). Table D1 (Appendix D) contains the results of 4 crash tests on steel lighting standards with slip base and 6 crash tests on steel poles with aluminum couplings.

The triangular slip base met the requirements of 1985 AASHTO Standard Specifications; however, in AGI Test 87F119 the change in velocity exceeded the 15 fps specified by the 1985 AASHTO specifications.

Three out of six tests on aluminum breakaway couplings also did not meet the 1985 AASHTO specifications. In AGI Test 87F075 the change in velocity exceeded the 15 fps criterion, and in AGI Test 87F055 the stub height exceeded the 4 in. stub height criterion. In

Test 87F054 the change in velocity and the stub height both exceeded the 1985 AASHTO criteria.

5.3.4 X Rays and Static Tests of Aluminum Couplings

5.3.4.1 Transpo Die-Cast Aluminum Couplings

X rays

Based on Caltrans specifications for controlling aluminum couplings which was written during the course of this research project, only couplings with a porosity defect level of 3 or better (ASTM E505 category A reference radiographs) were considered acceptable. The x ray results showed that all of the 20 couplings from the original lot (lot # 3222) failed to meet the minimum acceptable defect level, level 4 as defined in ASTM E505 category A reference radiographs. Ten out of eleven couplings from lot # 3558 passed the ASTM E505 level 2 defect severity; however, one of the couplings, #8, had porosity defects exceeding level 4. The porosity defect level in 5 out of 14 couplings in lot 210 was also unacceptable as they had level 4 porosity defects.

Tensile Tests

The results from tensile tests on Transpo die-cast aluminum couplings are shown in Table 5. The results showed that six of the eleven couplings tested failed to meet the minimum axial tensile load of 24000 lb as specified by Caltrans specifications (Appendix E). Two of the couplings from lot 210 had tensile strengths of below 14,000 lb. These low tensile strengths seemed to be due to a defect, other than gross porosity.

Restrained Shear Tests

Based on Caltrans specifications (Appendix E), the restrained shear strength of an individual coupling shall be 3600 lb minimum and 5500 lb maximum. Table 7, restrained shear tests results, shows that in one of the two restrained shear tests conducted on lot 210 of Transpo couplings, an unacceptable individual restrained shear value of 2960 lb was obtained.

Fatigue tests

Four Transpo die-cast aluminum couplings were subjected to a sinusoidal cyclic axial loading of +6.5 kips to +12 kips. This loading simulates a constant 80 mph wind load with a 30 percent gust factor on type 31 lighting standard. Also, two couplings were tested for a load range of -2.0 kips to 7.5 kips. There was no coupling failure after over 2 million cycles of loading in any of the tests. In samples No. 7 and No. 8, where the specimens were subjected to stress reversal loading (passing through zero load) considerable vertical movement was noted between threads of the anchor bar stub and those in the base of the coupling body. This movement was about 0.025 in. in specimen No. 7 and 0.017 in. in specimen No. 8. The thread play was present at the beginning of both tests, was fairly constant during testing, and did not cause any problems. One sample was subjected to cyclic loading from +9. kips to 16.8 kips and failed after 98,900 cycles of loading. Table 9 shows the summary of test results.

Corrosion Test

The results of one Transpo die-cast aluminum coupling and three

ALCOA extruded aluminum couplings subjected to a salt spray corrosion test (ASTM B177) are summarized in section 5.2.8.2, 5. No significant corrosion on the threaded regions of the stud, aluminum coupler body or nuts tested were observed in the salt spray test performed. Considerable corrosion (white rust) of the zinc metal (galvanizing) coating steel surfaces of the nuts, stud tops, all washers, and the simulated base plate was observed. The paint used to coat coupler body was very effective in preventing corrosion.

5.3.4.2 ALCOA Extruded Aluminum Couplings

Dimensional Checks

The dimensional checks performed on ALCOA's couplings (section 5.2.8.2, 1) revealed that the model 100-1 couplings did not comply with Caltrans dimensional requirements as their 1-in.-diameter galvanized steel studs were embedded only 1 in., not 1-3/8 in. as required by Caltrans Standard Plans (23).

Tensile Tests

Table 4 is the summary of tensile test results. In all cases the tensile strength of the ALCOA extruded aluminum breakaway coupling system exceeded the minimum 24,000 lb axial load specified in the Caltrans specifications for aluminum breakaway couplings. The three couplings tested had tensile strengths ranging from 31000 to 32600 lb, with a mean of 31,870 lb. As expected with the extruded aluminum sections, no flaws were present in the fractured planes.

Restrained Shear Tests

In three out of the four restrained shear tests conducted on ALCOA couplings (one test was invalid due to an inappropriate loading rate), the individual shear forces of the 6 couplings varied from 5,275 to 5800 lb, see Table 6. In 2 of 3 tests, restrained shear strengths of individual couplings were equal to or greater than 5,500 lb maximum shear strength (the upper limit set by engineering judgment) allowed by Caltrans specifications.

Fatigue Tests

Two out of three ALCOA couplings tested with a cyclic load of +6.5 kips to +12 kips (which simulates a constant 80 mph wind load with a 30 percent gust factor on type 31 lighting standard) failed at 1,986,000 and 717,900 cycles. Only one coupling tested under this load range exceeded the desired 2 million cycles. Table 8 is the summary of test results.

Corrosion Tests

No significant corrosion on the outside of ALCOA's aluminum shear nuts or the threaded regions of the stud, aluminum coupler bodies or nuts tested was observed after salt spray test performed. Considerable corrosion (white rust) of the zinc metal (galvanizing) coating steel surfaces of the nuts, stud tops, all washers, and the simulated base plate was observed.

No localized corrosion was apparent due to the various dissimilar metals present and in contact with each other (i.e., aluminum nuts, galvanized steel washers, stainless steel nuts, and aluminum coupler bodies). The paint used to coat coupler bodies was very effective in preventing corrosion. Overall, the corrosion resistance of ALCOA couplings when subjected to 1000 hours of ASTM's salt spray test was good (see section 5.2.8.2, 5 for the test results).

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APPENDIX A: Test Vehicle Equipment and Guidance System

The test vehicles were modified as follows for the seven crash tests:

The test vehicle gas tank was disconnected from the fuel supply line and drained. Extra weight was not needed, so dry ice was placed in the empty tank to inhibit combustion. A one-gallon safety gas tank was installed in the trunk compartment and connected to the fuel supply line.

Two 12-volt wet cell lead acid motorcycle-type batteries were mounted in the car to supply power for the test equipment in the car.

The accelerator pedal was linked to a small cylinder which opened the throttle. The piston was activated by a manually-thrown switch mounted on the side rear fender of the test vehicle. The piston was connected to the same CO_2 tube used for the brake system, but a separate regulator was used to control the pressure. The car was placed in the drive position on the automatic transmission.

A speed control device, which was connected between the negative side of the coil and the battery of the vehicle, regulated the speed of the test vehicle based on the speedometer cable output. This device was calibrated prior to the test by conducting a series of trial runs through a speed trap composed of two tape switches set a known distance apart and connected to a digital timer.

A cable guidance system was used to direct the vehicle into the lighting standard. The guidance cable, anchored at each end of the vehicle path to a threaded coupler embedded in a concrete footing, passed through a guide bracket bolted to the spindle of one of the front wheels. A steel knockoff bracket, to which the end of the cable closest to the lighting standard was anchored, projected high enough to knock off the guide bracket thereby releasing the vehicle from the guidance cable prior to impact.

A microswitch was mounted below the front bumper and connected to the ignition system. A trip plate placed on the ground near the impact point triggered the switch when the car passed over it. This opened the ignition circuit, cut the vehicle engine prior to impact and released the sliding weight from the electromagnet so that the weight was free to travel slightly before the instant of impact.

A solenoid valve-actuated CO_2 system was used for remote braking after impact or for emergency braking at any other time. Part of this system was a cylinder with a piston which was attached to the brake pedal. The pressure used to operate the piston was regulated according to the test vehicle weight. This allowed the vehicle to stop without locking up the wheels.

The remote brakes were controlled at the console trailer by using an instrumentation cable connected between the vehicle and the electronic instrumentation trailer and a cable from the trailer to the console trailer. Any loss of continuity in these cables caused an automatic activation of the brakes and ignition cutoff. Remote activation of the brakes would also turn off the ignition.

Figure A1 shows the vehicle dimensions.

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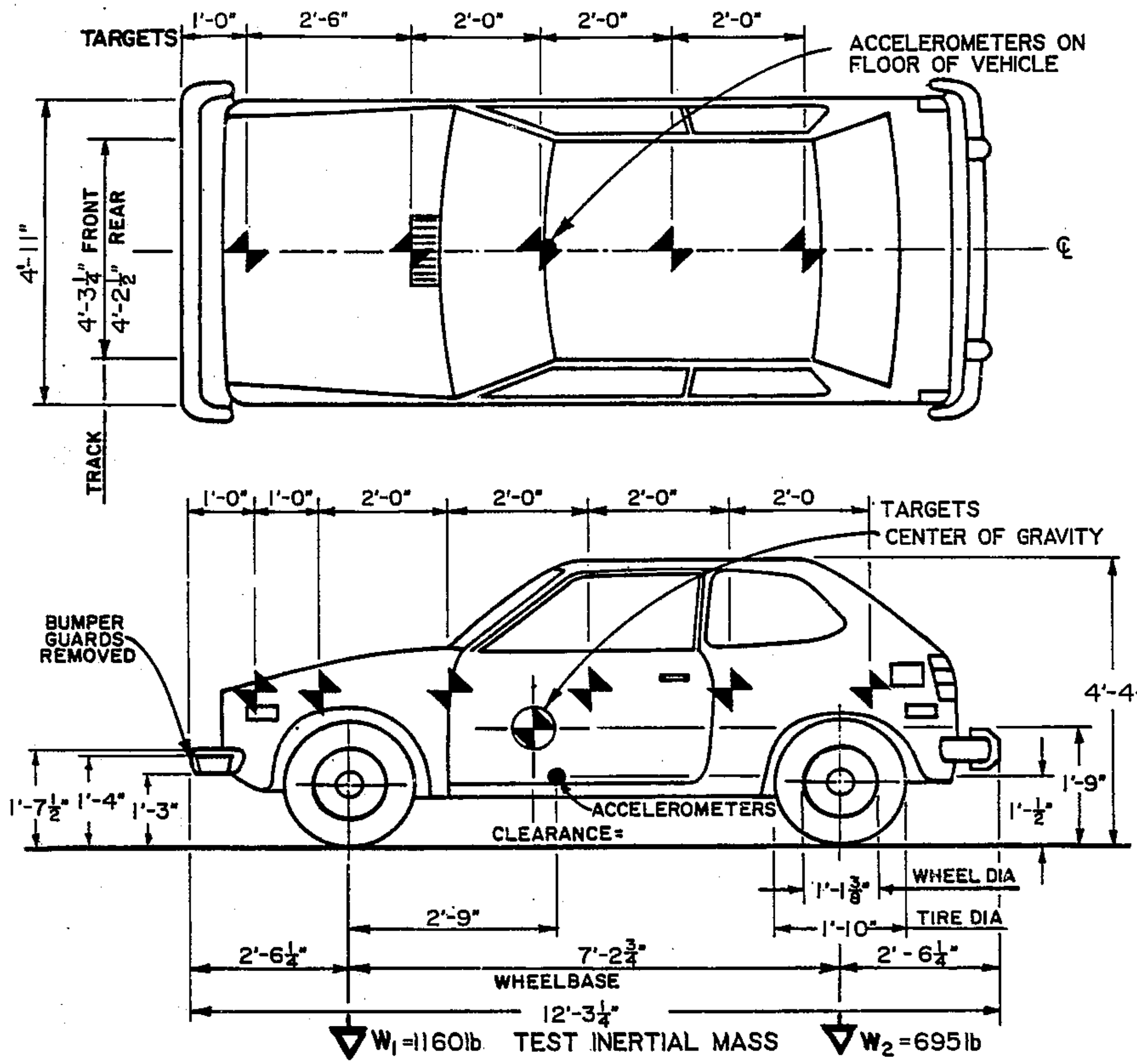


Figure A1. Test Vehicle Dimensions

APPENDIX B: Photo-Instrumentation

Several high-speed movie cameras were used to record the impact during crash tests. The types of cameras used and their locations are shown in Figures B1 through B5. The cameras were electrically activated from a central control console located adjacent to the impact area except for three which had their own battery power and were turned on by three separate operators.

All high-speed cameras were equipped with timing light generators which exposed reddish timing pips on the film at a rate of 1,000 per second. The pips were used to determine camera frame rates and to establish time/sequence relationships. Data from the high speed movies were reduced on a Vanguard Motion Analyzer. Some procedures used to facilitate data reduction for the test are listed as follows:

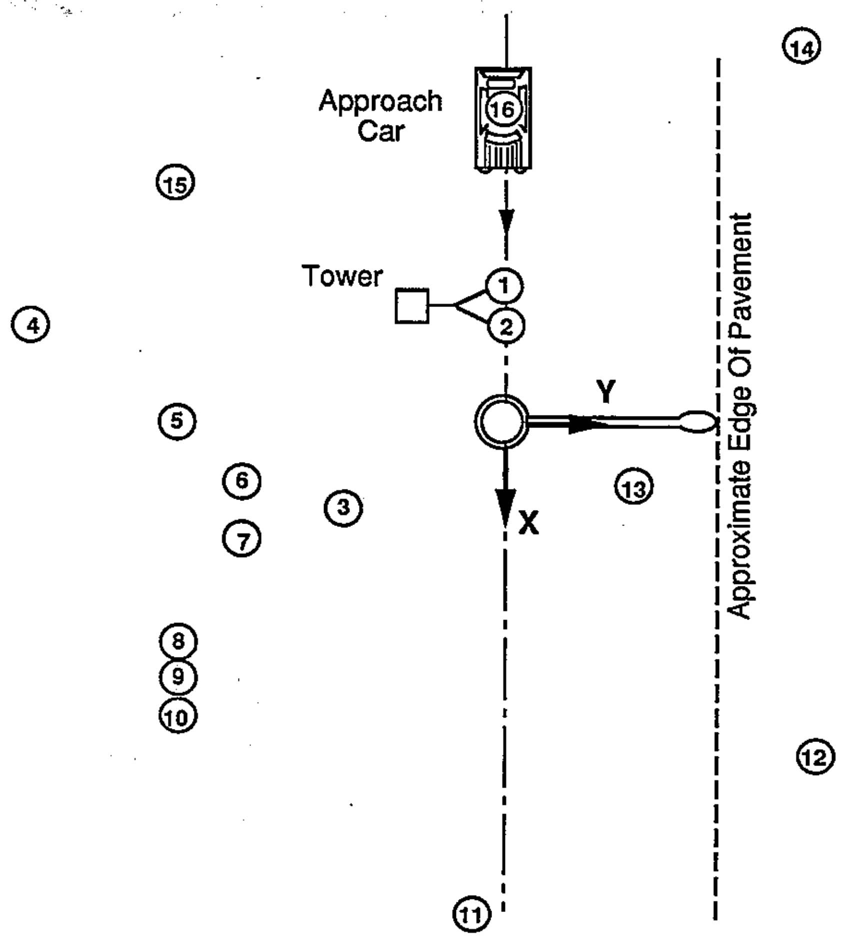
1- Butterfly targets were attached to the top and sides of the test vehicle. Figure A1 (Appendix A) shows the target locations. The targets established scale factors and horizontal and vertical alignment. The area of impact on the lighting standard was outlined using contrasting colors of tape, Figure B6.

2- Flashbulbs, mounted on the test vehicle, were electronically triggered to establish (a) initial vehicle/lighting standard contact (b) application of the vehicle brakes and (c) beginning and ending of sliding weight travel. The impact flashbulbs had a delay of several milliseconds before lighting up.

3- Five tape switches, placed at ten-foot intervals, were attached to the ground perpendicular to the path of the impacting vehicle beginning about five feet from impact. Flashbulbs were activated sequentially when the tires of the test vehicle rolled over the tape switches. The flashbulb stand was placed in view of most of the data cameras or made visible to the tower cameras through the use of mirrors. The flashing bulbs were used to correlate the cameras with the impact events and to calculate the impact speed independent of the electronic speed trap. The tape switch layout is shown in Figure B7.

4- Additional coverage of the impacts was obtained by a 70mm Hulcher sequence camera and a 35mm Hulcher sequence camera (both operating at 20 frames per second). Documentary coverage of the tests consisted of normal-speed movies and still photographs taken before and after impact.

5- A sliding weight device was mounted on all test cars to determine the rattle-space time (the time it took for the weight to travel two feet). The weight contained ball bearings which rolled along a smooth rod. The weight was held in place on the left end of the rod by an electromagnet before impact. The front bumper switch on the car which cut the ignition about two feet from impact also cut off the current to the electromagnet. The weight was then free to slide forward for a two-foot distance on the rod after impact. Flashbulbs mounted on the device were activated when the weight began to move and also when it reached the end of its travel. The flashbulbs were more visible to distant data cameras than the sliding weight. The rattle-space time was determined from the high-speed movie film. This data would only be used if accelerometer data failed.

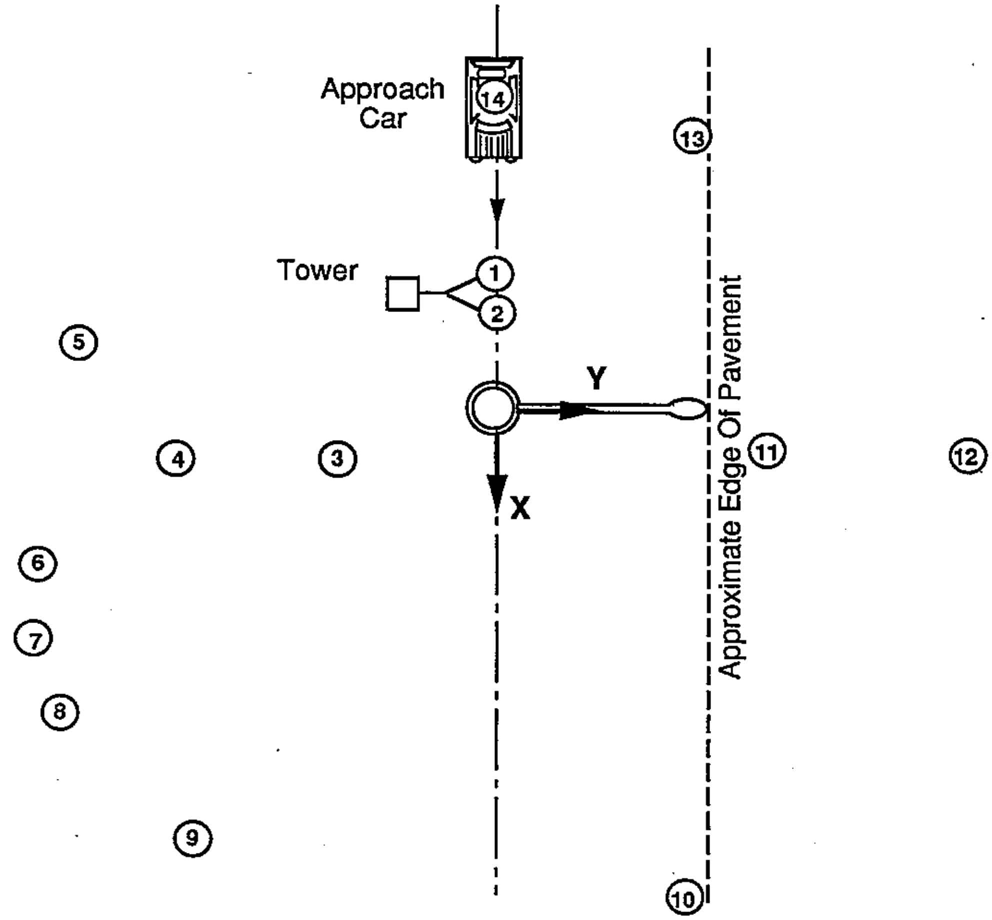


CAMERA No.	CAMERA AND LENS		COORDINATES (FT.)	
			X	Y
1	16mm Photo-Sonic	13mm	-19	0
2	16mm Photo-Sonic	13mm	-17	0
3	16mm Redlake Locam	50mm	3.5	-16.5
4	16mm Photo-Sonic	13mm	-18	-102.8
5	16mm Redlake Locam	50mm	0.0	-50.3
6	35mm Hulcher	105mm	2.5	-37.8
7	70mm Hulcher	150mm	4.5	-37.8
8	16mm Redlake Locam	55mm	13	-50.3
9	16mm Bolex	50mm	14	-50.3
10	16mm Photo-Sonic	50mm	15	-50.3
11	16mm Photo-Sonic	100mm	198	-5.5
12	16mm Redlake Locam	75mm	21.5	28.5
13	16mm Photo-Sonic	100mm	4.5	16.5
14	16mm Photo-Sonic	13mm	-129	28
15	16mm Photo-Sonic	13mm	25	-50.3
16	16mm Photo-Sonic	7.5mm	in the car	---

NOTE:

Nominal camera speeds in frames per second were 20 for Hulchers, 24 for Bolex and 400 for all others

Figure B1. Camera Data and Layout - Test 401

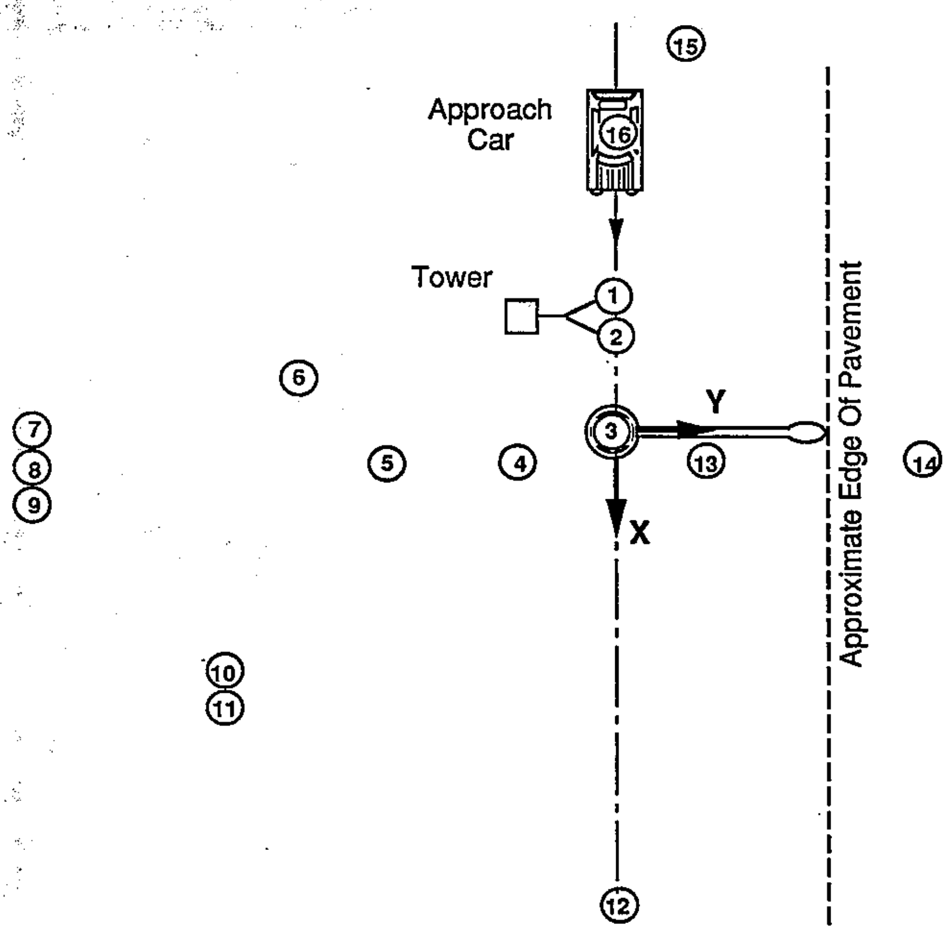


CAMERA No.	CAMERA AND LENS		COORDINATES (FT.) X	Y
1	16mm Photo-Sonic	13mm	-19	0
2	16mm Photo-Sonic	13mm	-17	0
3	16mm Photo-Sonic	13mm	4	-17.5
4	16mm Redlake Locam	50mm	4	-46.5
5	16mm Photo-Sonic	50mm	-6	-82.5
6	16mm Redlake Locam	50mm	15	-95.5
7	35mm Hulcher	105mm	25	-95.5
8	70mm Hulcher	150mm	28	-91.5
9	16mm Bolex	50mm	57	-46.5
10	16mm Redlake Locam	100mm	210	10
11	16mm Photo-Sonic	100mm	3	14.5
12	16mm Photo-Sonic	50mm	3	59
13	16mm Redlake Locam	13mm	-91	10
14	16mm Photo-Sonic	7.5mm	in the car	---

NOTE:

Nominal camera speeds in frames per second were 20 for Hulchers, 24 for Bolex and 400 for all others

Figure B2. Camera Data and Layout - Test 402

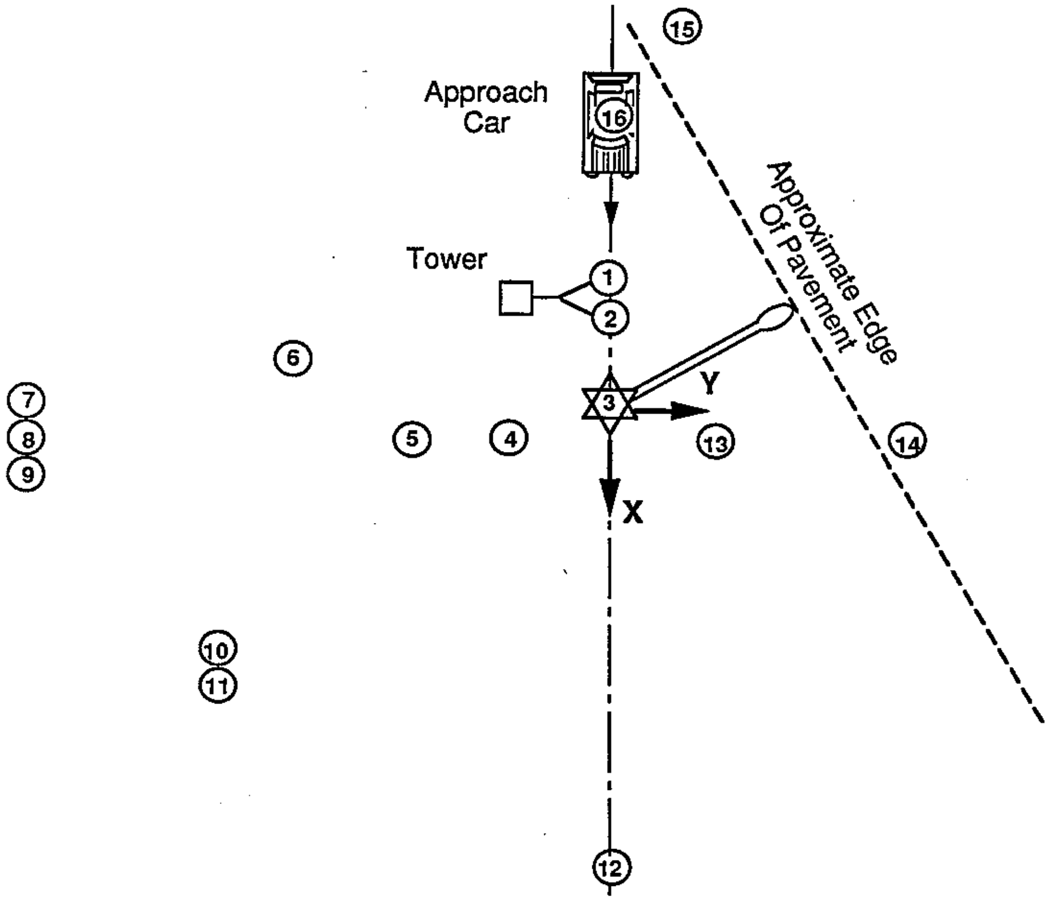


CAMERA No.	CAMERA AND LENS		COORDINATES (FT.)	
			X	Y
1	16mm Photo-Sonic	13mm	-19	0
2	16mm Photo-Sonic	13mm	-17	0
3	16mm Redlake Locam		0	0
4	16mm Redlake Locam	75mm	4	-18
5	16mm Redlake Locam	50mm	4	-45
6	16mm Photo-Sonic	13mm	-6	-70
7	35mm Bolex	30mm	0	-120
8	16mm Photo-Sonic	50mm	2	-120
9	16mm Redlake Locam	30mm	5	-120
10	35mm Hulcher	105mm	25	-90
11	70mm Hulcher	150mm	26	-90
12	16mm Photo-Sonic	13mm	250+	0
13	16mm Photo-Sonic	50mm	4	18
14	16mm Redlake Locam	50mm	4	60
15	16mm Photo-Sonic	100mm	-90	10
16	16mm Photo-Sonic	7.5mm	in the car	---

NOTE:

Nominal camera speeds in frames per second were 20 for Hulchers, 24 for Bolex and 400 for all others

Figure B3. Camera Data and Layout - Test 403

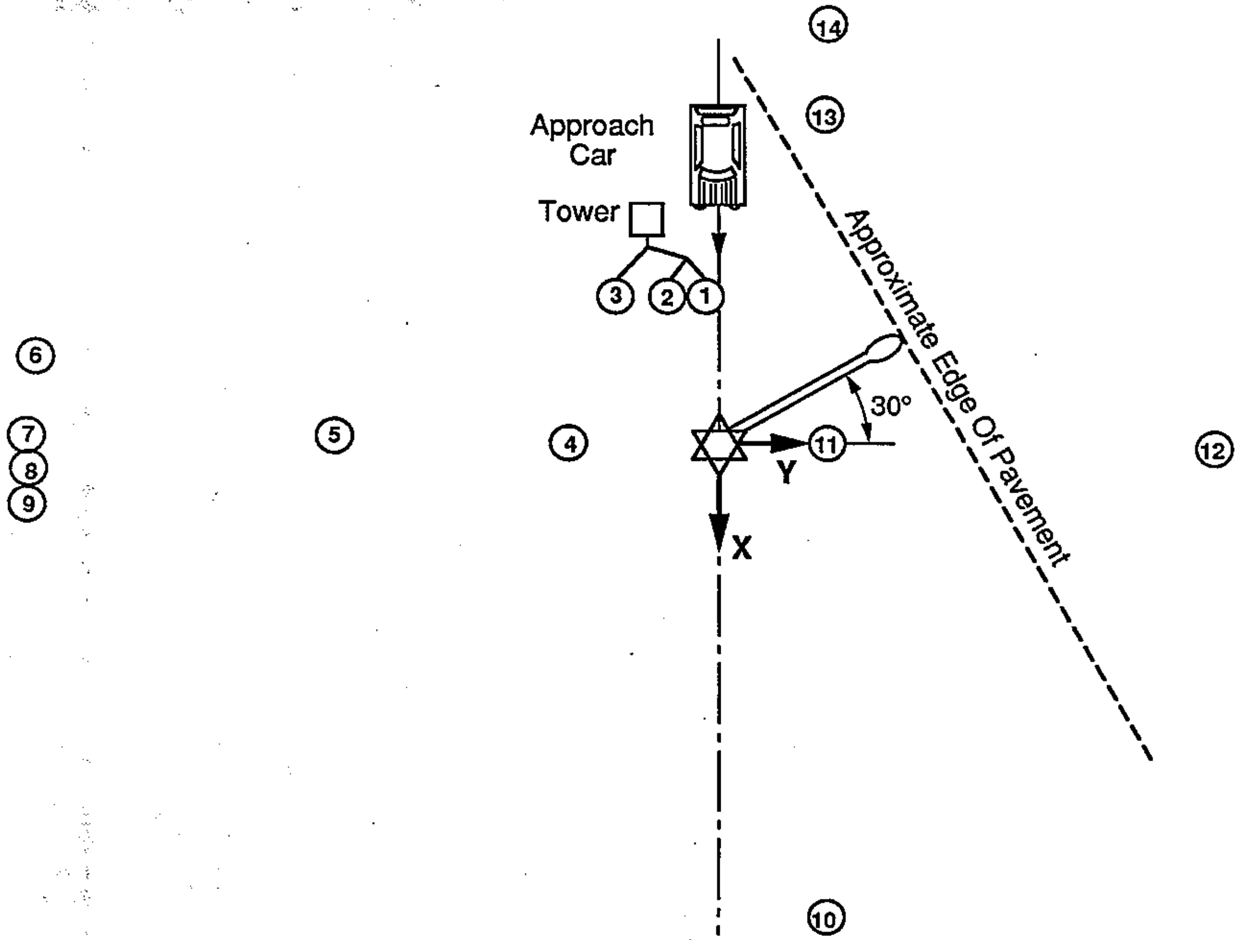


CAMERA No.	CAMERA AND LENS		COORDINATES (FT.)	
			X	Y
1	16mm Photo-Sonic	13mm	-19	0
2	16mm Photo-Sonic	13mm	-17	0
3	16mm Redlake Locam		0	0
4	16mm Redlake Locam	75mm	4	-18
5	16mm Redlake Locam	50mm	4	-45
6	16mm Photo-Sonic	13mm	-6	-70
7	35mm Bolex	30mm	0	-120
8	16mm Photo-Sonic	50mm	2	-120
9	16mm Redlake Locam	30mm	5	-120
10	35mm Hulcher	105mm	25	-90
11	70mm Hulcher	150mm	26	-90
12	16mm Photo-Sonic	13mm	250+	0
13	16mm Photo-Sonic	50mm	4	18
14	16mm Redlake Locam	50mm	4	60
15	16mm Photo-Sonic	100mm	-90	10
16	16mm Photo-Sonic	7.5mm	in the car	---

NOTE:

Nominal camera speeds in frames per second were 20 for Hulchers, 24 for Bolex and 400 for all others

Figure B4. Camera Data and Layout - Test 404



CAMERA No.	CAMERA AND LENS		COORDINATES (FT.)	
			X	Y
1	16mm Photo-Sonic	13mm	-18.6	-2
2	16mm Photo-Sonic	13mm	-18.6	-3
3	16mm Photo-Sonic	13mm	-18.6	-11.9
4	16mm Redlake Locam	25mm	0.0	-18.5
5	16mm Redlake Locam	50mm	0.0	-54.8
6	16mm Photo-Sonic	50mm	-10.2	-92.2
7	16mm Photo-Sonic	50mm	1	-93.2
8	35mm Hulcher	50mm	5.5	-92.5
9	70mm Hulcher	150mm	9	-92.5
10	16mm Photo-Sonic	13mm	194.9	13.5
11	716mm Photo-Sonic	100mm	0	13.5
12	16mm Redlake Locam	35mm	0	61
13	16mm Photo-Sonic		-61.6	13.5
14	16mm Photo-Sonic		-141.5	13.5

NOTE:
Nominal camera speeds in frames per second were 20 for Hulchers, 24 for Bolex and 400 for all others

Figure B5. Camera Data and Layout - Tests 405, 406, and 407

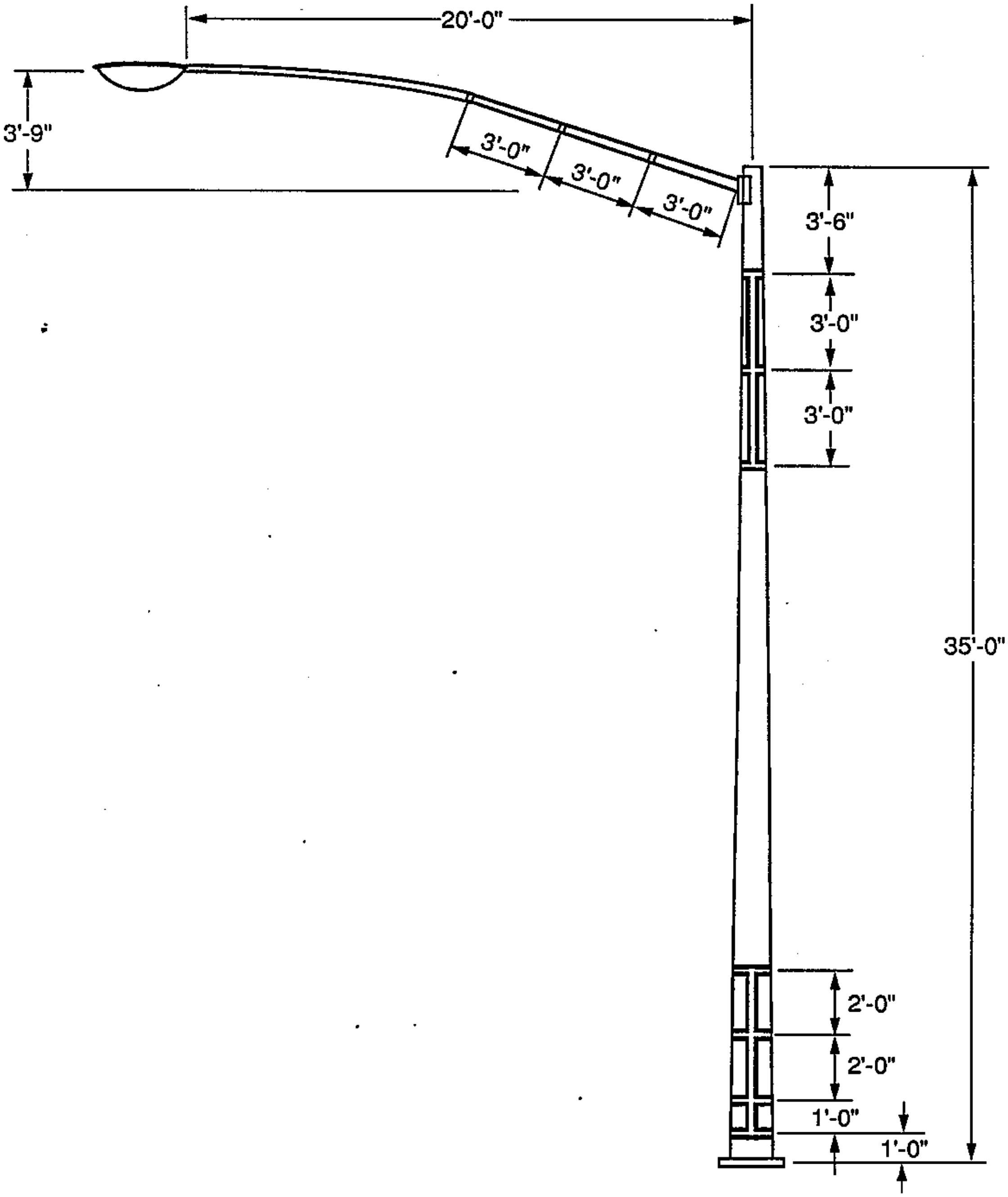


Figure B6. Targeting on Lighting Standard

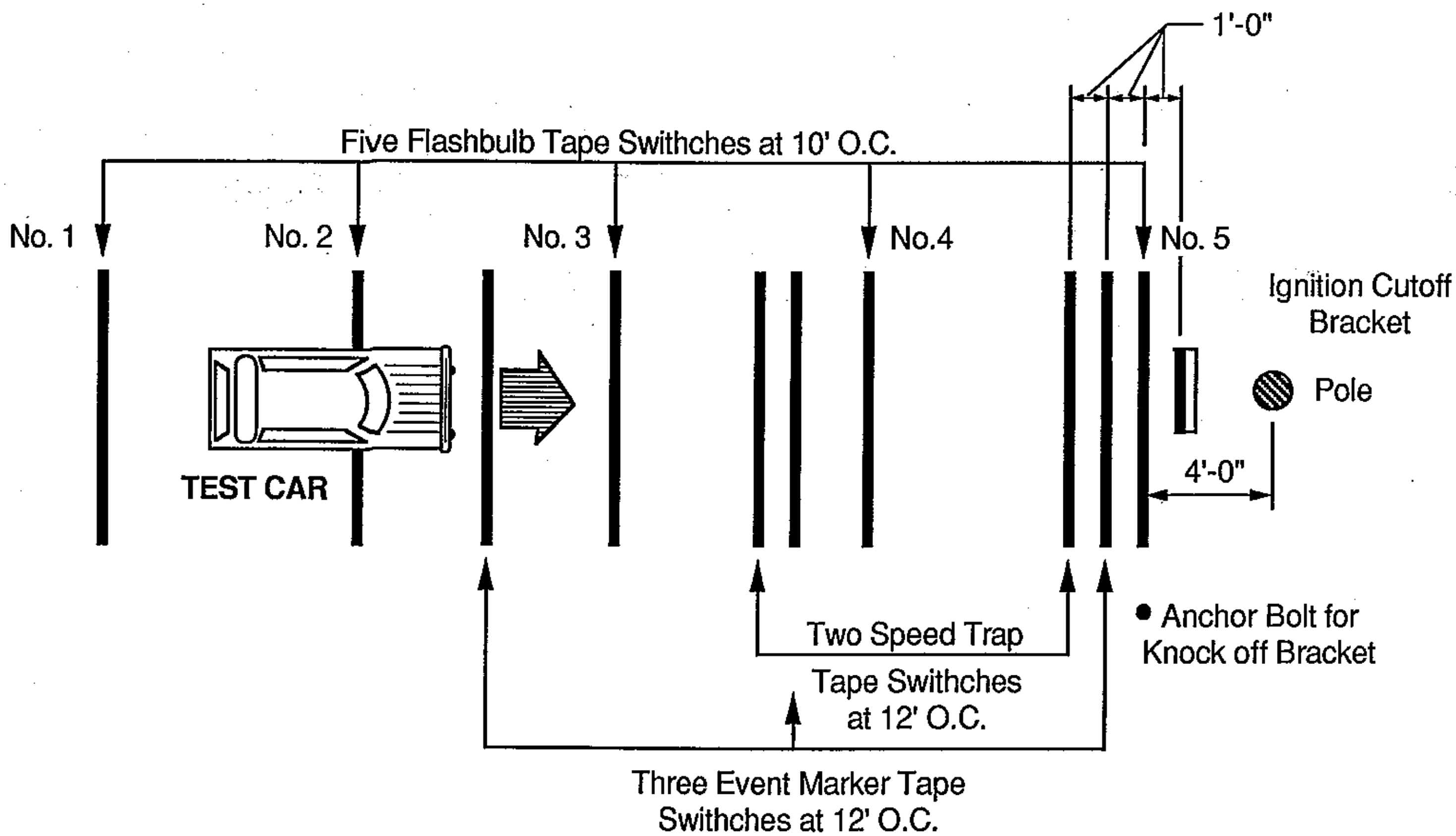


Figure B7. Tape Switch Dimensions

APPENDIX C: Electronic Instrumentation and Data

A total of six accelerometers were used for acceleration measurements. Three unbonded strain gage accelerometers (Statham) were mounted on the floorboard of the test vehicle at the center of gravity in the longitudinal and lateral directions. They were oriented in the longitudinal, lateral and vertical directions. These accelerometers were mounted on a small rectangular steel plate which was welded to the floorboard close to the vehicle center of gravity in the horizontal plane. Also, three Endevco Model 2262-200 piezo-resistive accelerometers were mounted in the head of the dummy seated on the driver's seat.

Data from the accelerometers in the test vehicle were transmitted through a 1,000-foot Belden #8776 umbilical cable connecting the vehicle to a 14-channel Hewlett-Packard 3924C magnetic tape recording system. This recording system was in an instrumentation trailer at the test control area.

Three pressure-activated tape switches were placed on the ground in front of the light standard. They were spaced at carefully measured intervals of 12 feet. When the test vehicle tires passed over them, the switches produced sequential impulses or "event blips" which were recorded concurrently with the accelerometer signals on the tape recorder and served as "event markers". A tape switch on the front bumper of the car closed at the instant of impact and activated flash bulbs mounted on the car. The closure of the bumper switch also put a "blip" or "event marker" on the recording tape. A time cycle was also recorded continuously on the tape with a frequency of 500 cycles per second. The impact velocity of the vehicle could be determined from the tape switch impulses and the timing cycles. Two other tape switches, connected to digital readout equipment, were placed twelve feet apart just upstream of the light standard to determine the impact speed of the test vehicle immediately after the test. The tape switch layouts are shown in Figure B7, Appendix B.

All accelerometer data were processed on a Norland Model 3001 Waveform Analyzer, the primary means of data reduction. The analyzer digitized and manipulated the raw data, printed results and plotted various curves. These data curves are shown in Figures C1 through C28. The occupant impact velocity is theoretical; however, on the plot of distance versus time, the curves can be visualized as representing the car windshield and the driver's head. It is assumed that the head starts out two feet behind the windshield. The point where the curves cross represents the impact between the head and the windshield because the windshield was slowed down from the impact velocity and the head was not. The time when the windshield/head impact occurs (rattle-space time) is carried to the plot of velocity versus time. The occupant impact velocity is the difference between the vehicle impact velocity and the vehicle velocity at the end of rattle-space time.

TEST NUMBER
401.00
LIGHTWEIGHT
LIGHTING
STANDARD
AUG. 25 1982

MAX. 50 MS
AVER. ACCEL.
FOR CAR (G)-

VERTICAL---
-.84539
FROM TIME(S)
8.7500E-02

LONGITUDINAL
-3.8136
FROM TIME(S)
1.5000E-03

LATERAL
-.80426
FROM TIME(S)
3.1000E-02

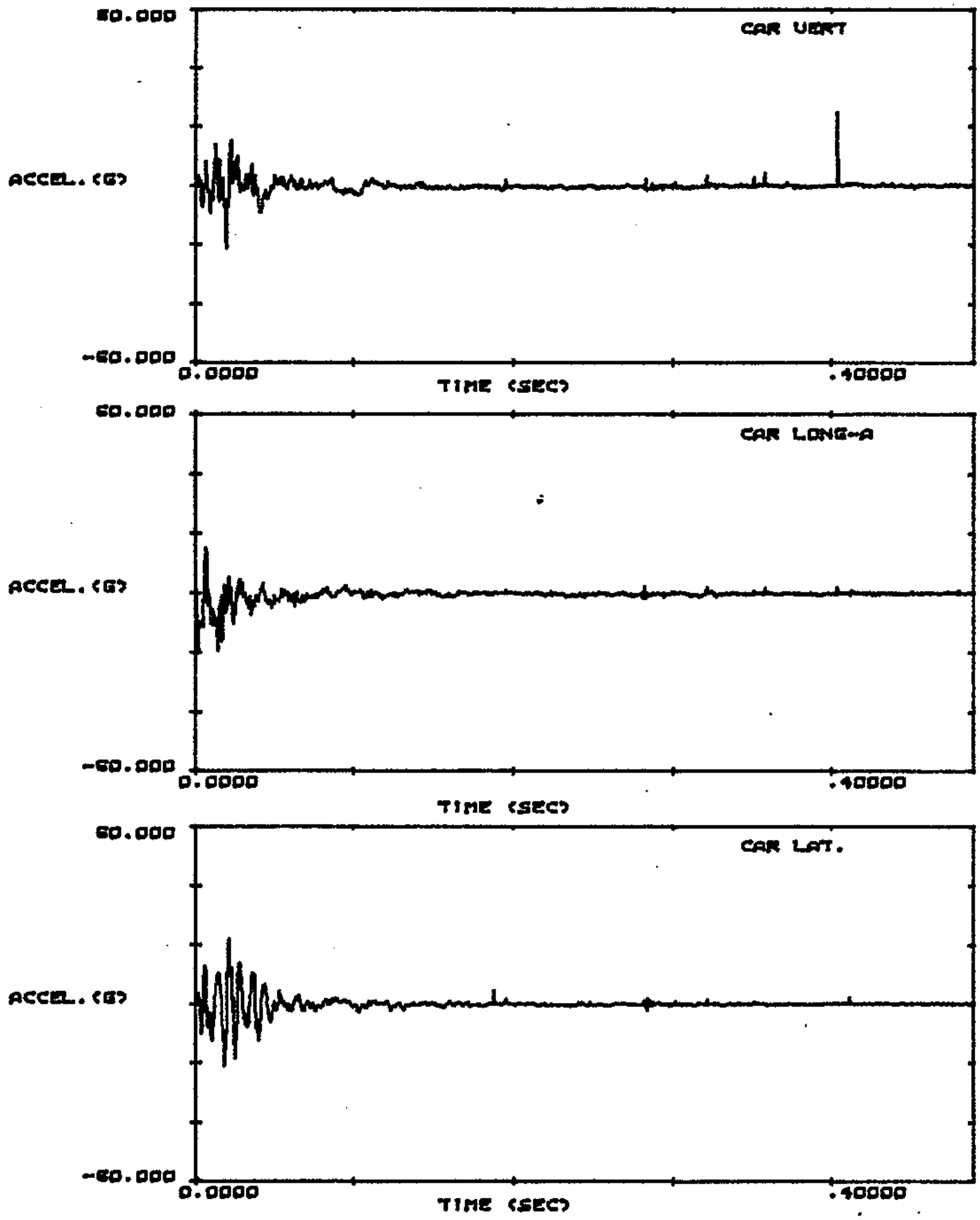


Figure C1

TEST NUMBER

401.00

LIGHTWEIGHT

LIGHTING

STANDARD

AUG. 25 1982

CAR WEIGHT

(POUNDS)-

1890.0

MASS(SLUGS)-

5.8696E-02

KINETIC

ENERGY (KE)

EQUALS 1/2

MASS TIMES

THE SQUARE

OF THE VEL.

AT IMPACT

VEL. (FPS)-

85.947

VEL. (MPH)-

58.600

K.E. (FT-K)-

216.79

DISSIPATED

KE (AT END

OF ANALYSIS)

51.379

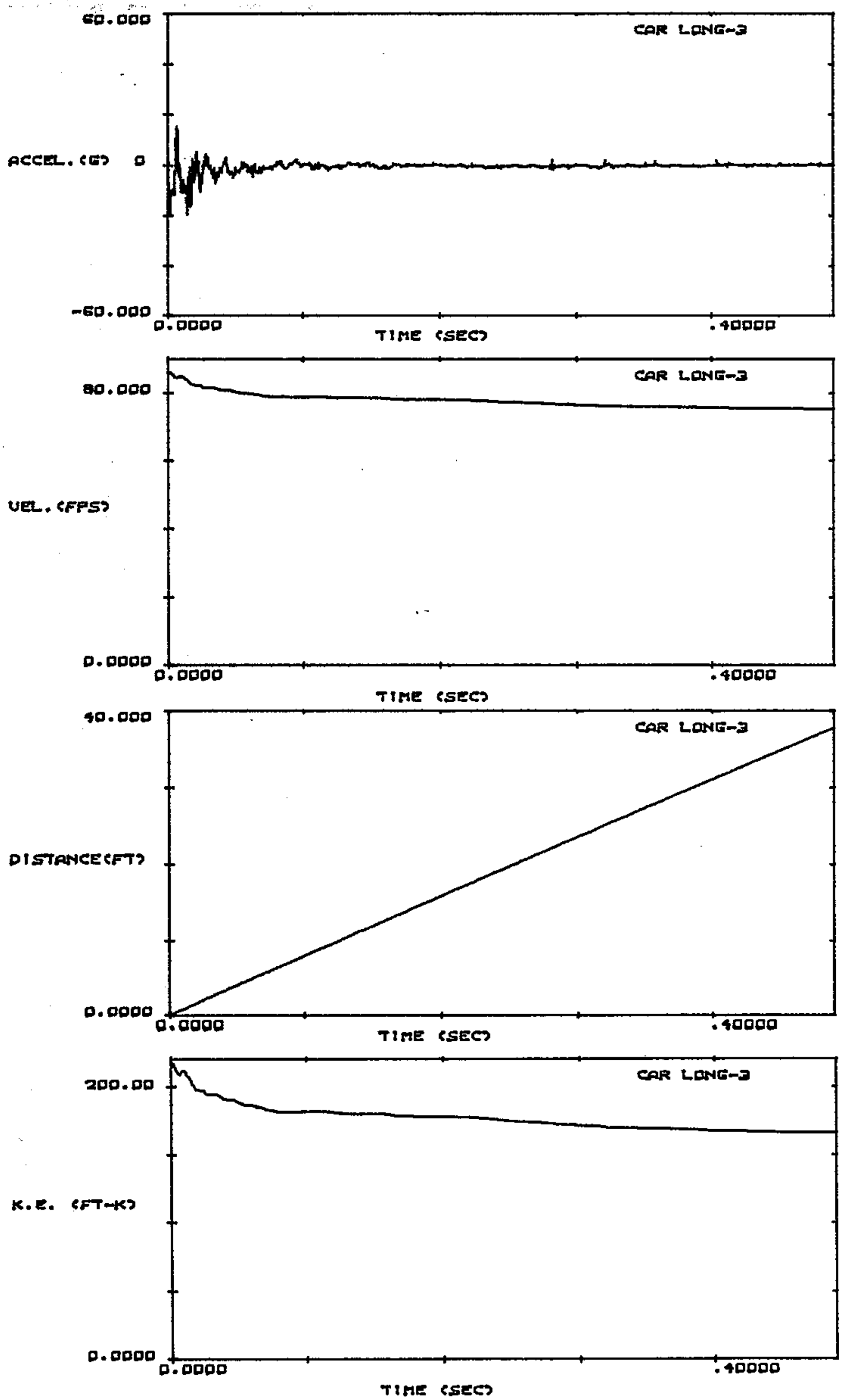


Figure C2

TEST NUMBER
401.00
LIGHTWEIGHT
LIGHTING
STANDARD
AUG. 25 1982

CAR IMPACT
VELOCITY
(FPS)-
85.948

AT CAR
DISTANCE(FT)
21.895
OCCUPANT
IMPACT
OCCURS

OCCUPANT
IMPACT
VELOCITY
(FPS)-
9.3681
OCCURS AT
.27800
SEC. AFTER
CAR IMPACT

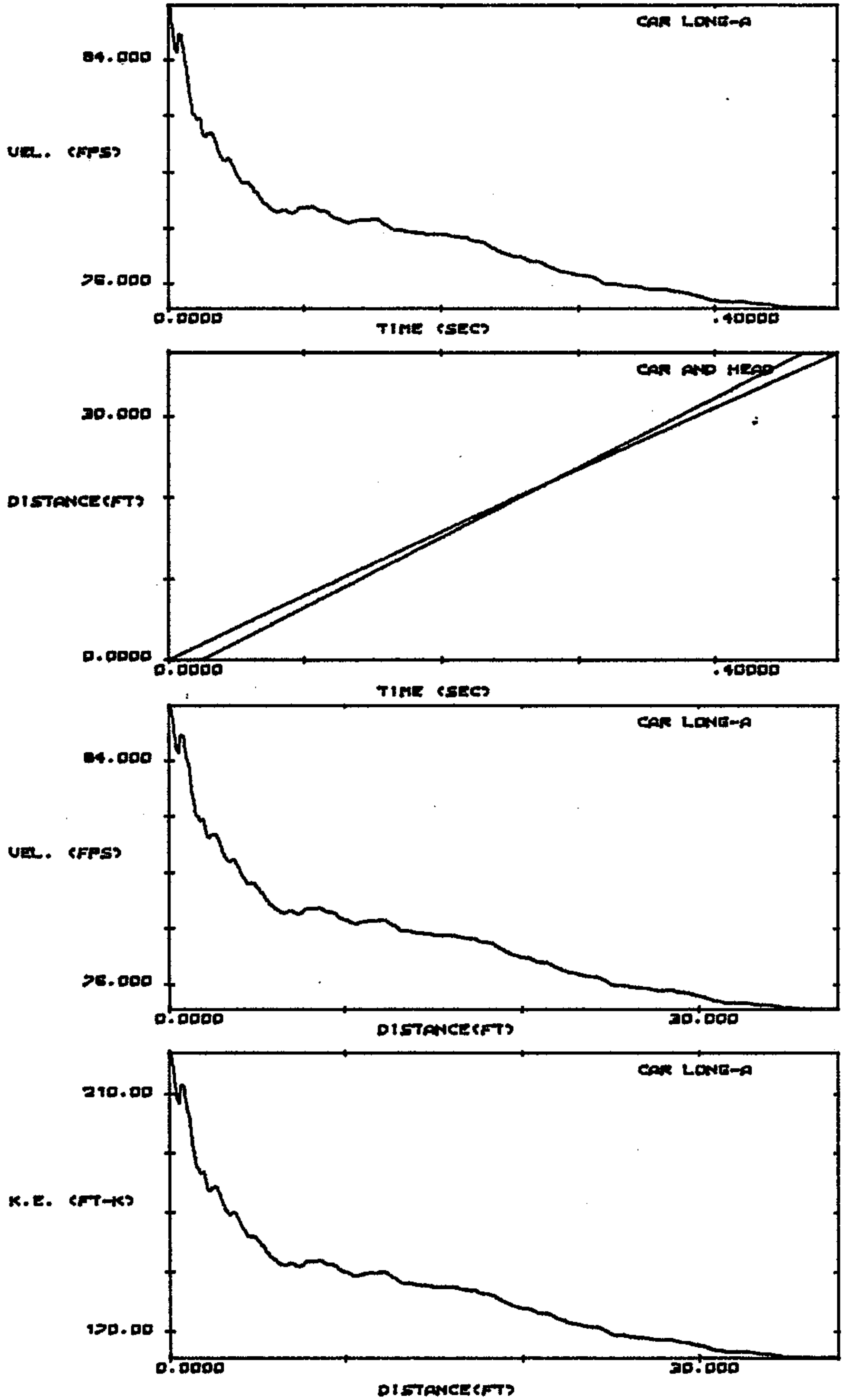


Figure C3

TEST NUMBER

401.00

LIGHTWEIGHT

LIGHTING

STANDARD

AUG. 25 1982

MAXIMUM

50 MS AVER.

DUMMY HEAD

RESULTANT

ACCEL. (G)-

2.4548

FROM TIME(S)

.34700

TO TIME(S)

.39700

HEAD INJURY

CRITEREON-

1.8107

FROM TIME(S)

7.3500E-02

TO TIME(S)

.40400

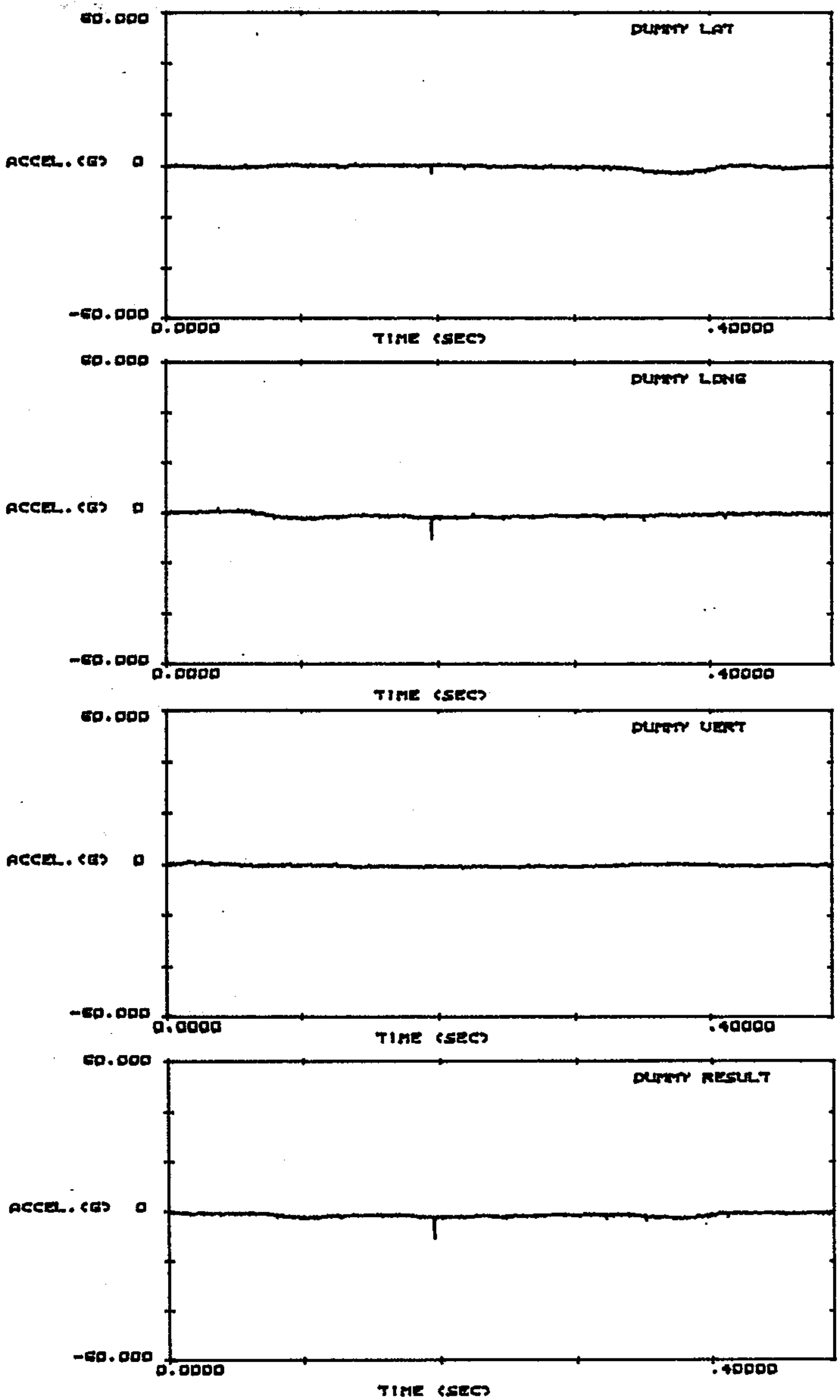


Figure C4

TEST NUMBER
402.00
LIGHTWEIGHT
LIGHTING
STANDARD
OCT. 13 1982

MAX. 50 MS
AVER. ACCEL.
FOR CAR (G)-

VERTICAL---
-.74285
FROM TIME(S)
8.9500E-02

LONGITUDINAL
-3.1896
FROM TIME(S)
2.5000E-03

LATERAL
.22637
FROM TIME(S)
3.5000E-02

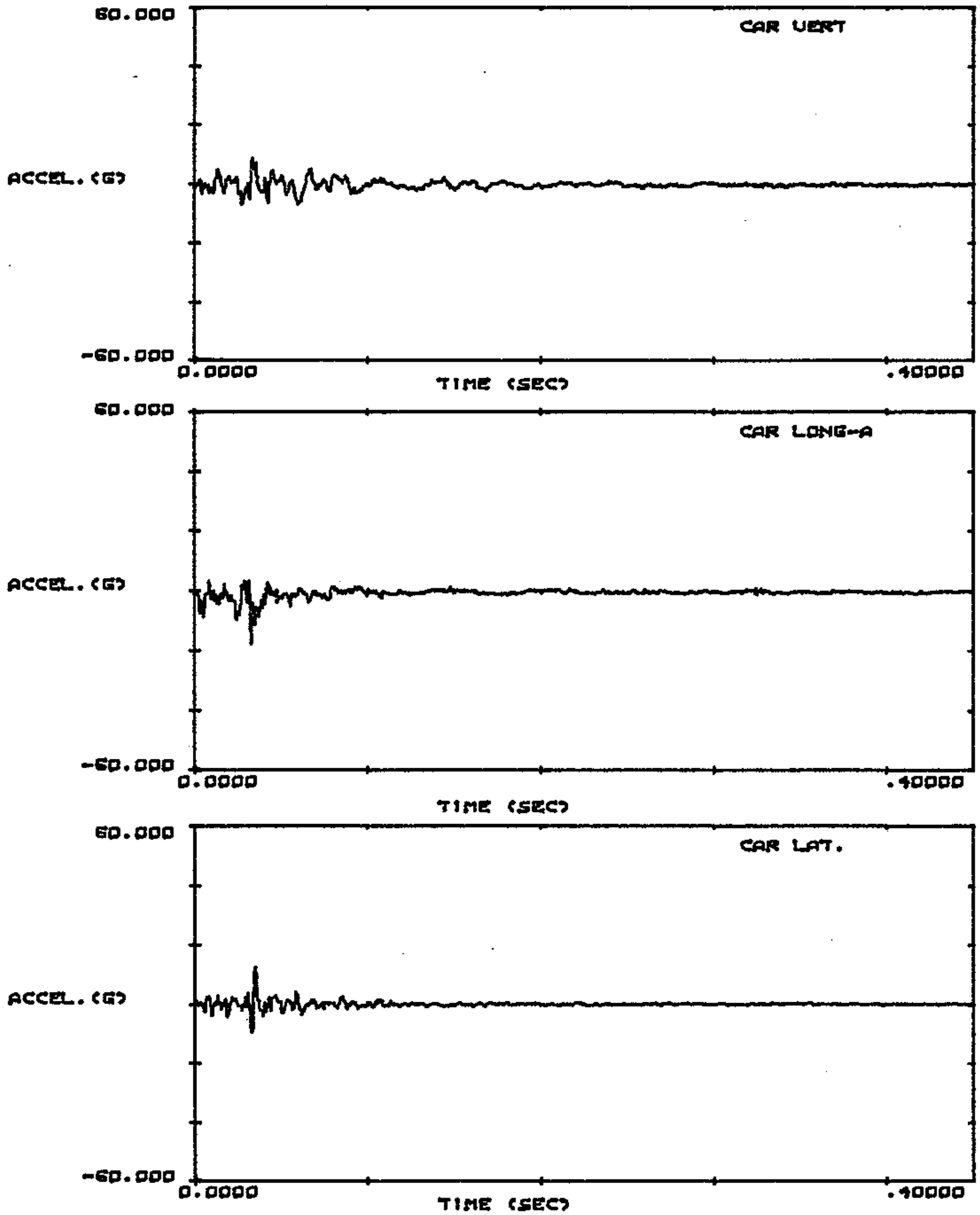


Figure C5

TEST NUMBER
402.00
LIGHTWEIGHT
LIGHTING
STANDARD
OCT. 13 1982

CAR WEIGHT
(POUNDS)-
1850.0
MASS(SLUGS)-
5.7453E-02

KINETIC
ENERGY (KE)
EQUALS 1/2
MASS TIMES
THE SQUARE
OF THE VEL.

AT IMPACT
VEL. (FPS)-
28.688
VEL. (MPH)-
19.560
K.E. (FT-K)-
23.642

DISSIPATED
KE (AT END
OF ANALYSIS)
16.818

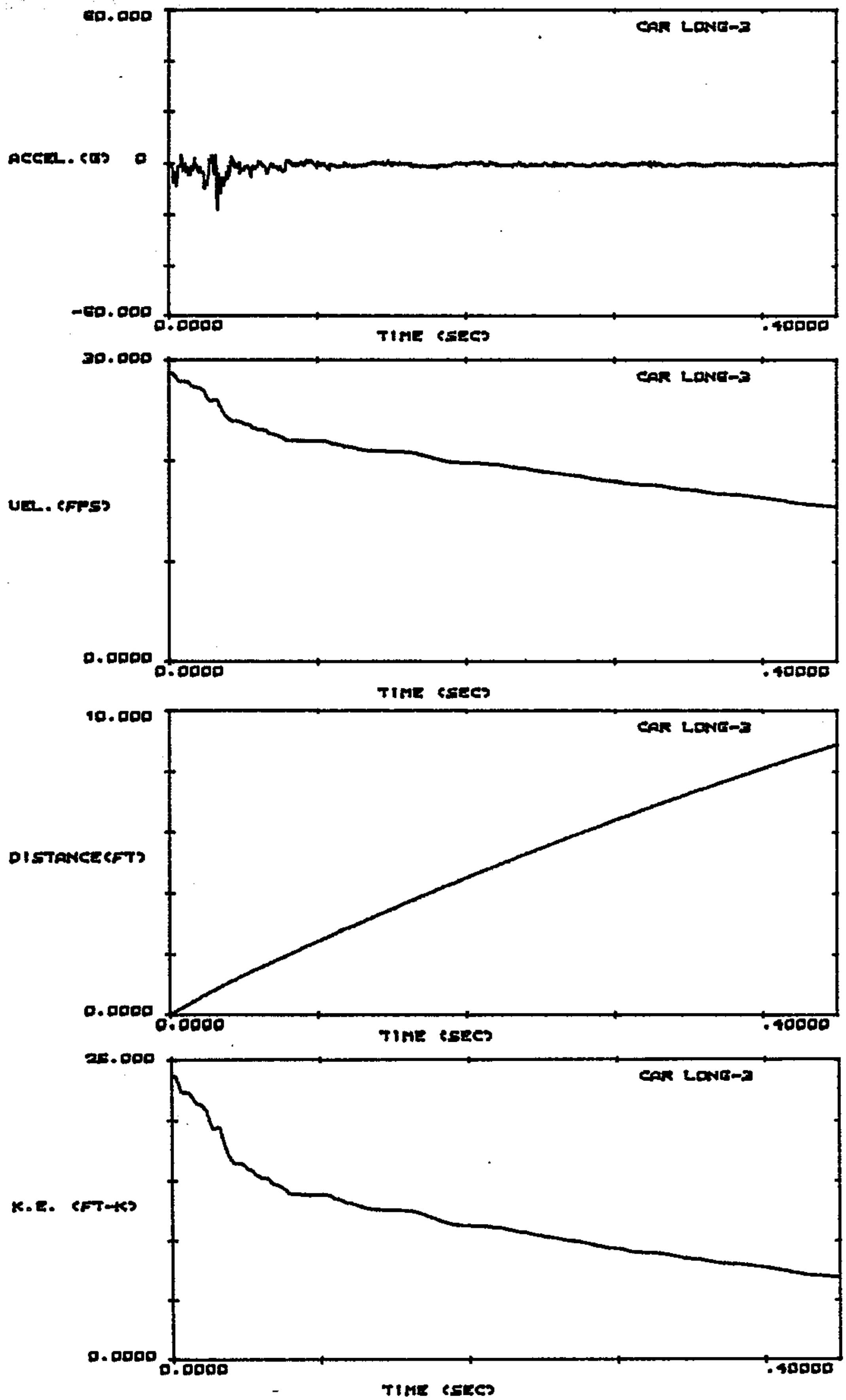


Figure C6

TEST NUMBER
402.00
LIGHTWEIGHT
LIGHTING
STANDARD
OCT. 13 1982

CAR IMPACT
VELOCITY
(FPS)-
28.688

AT CAR
DISTANCE(FT)
6.0751
OCCUPANT
IMPACT
OCCURS

OCCUPANT
IMPACT
VELOCITY
(FPS)-
10.412
OCCURS AT
.28150
SEC. AFTER
CAR IMPACT

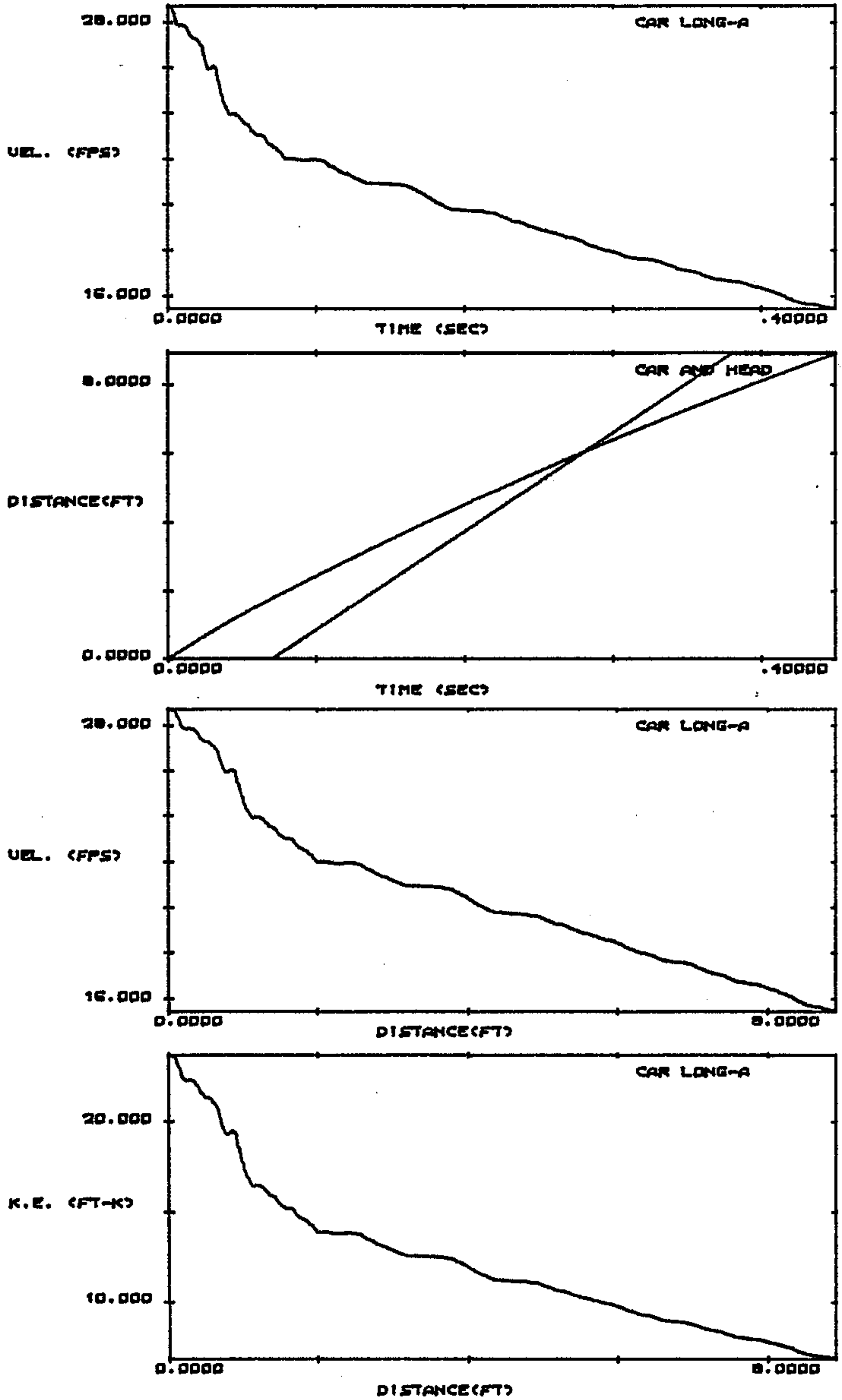


Figure C7

TEST NUMBER
402.00
LIGHTWEIGHT
LIGHTING
STANDARD

OCT. 13 1982

MAXIMUM
50 MS AVER.
DUMMY HEAD
RESULTANT
ACCEL. (G)-
2.0986
FROM TIME(S)
.18100
TO TIME(S)
.23100

HEAD INJURY
CRITEREON-
.79604
FROM TIME(S)
8.1500E-02
TO TIME(S)
.43250

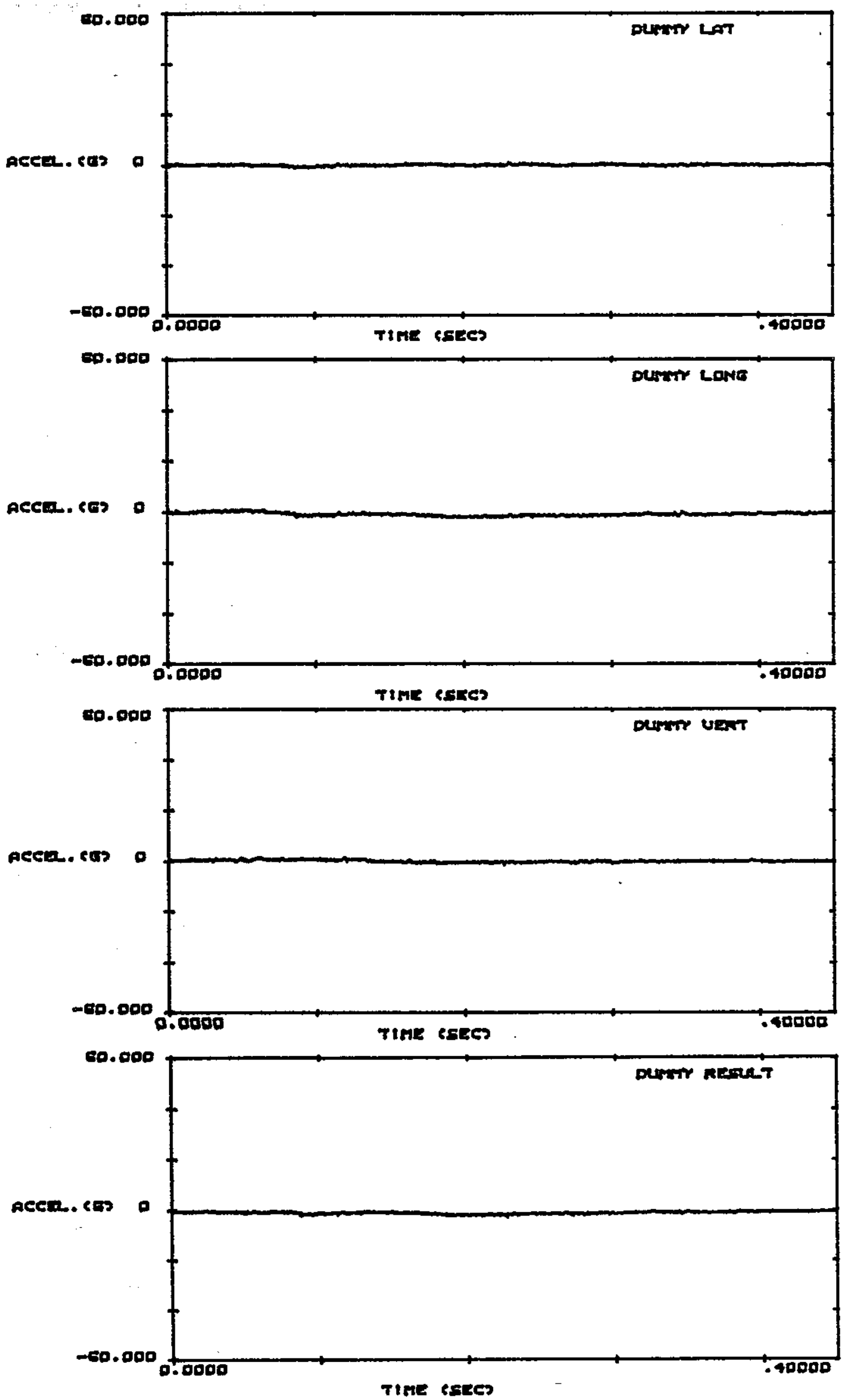


Figure C8

TEST NUMBER

403.00

LIGHTWEIGHT

LIGHTING

STANDARD

JULY 20 1983

MAX. 50 MS

AVER. ACCEL.

FOR CAR (G)-

VERTICAL---

1.1345

FROM TIME(S)

2.0500E-02

LONGITUDINAL

-5.7882

FROM TIME(S)

1.0000E-03

LATERAL---

-2.1308

FROM TIME(S)

3.0000E-02

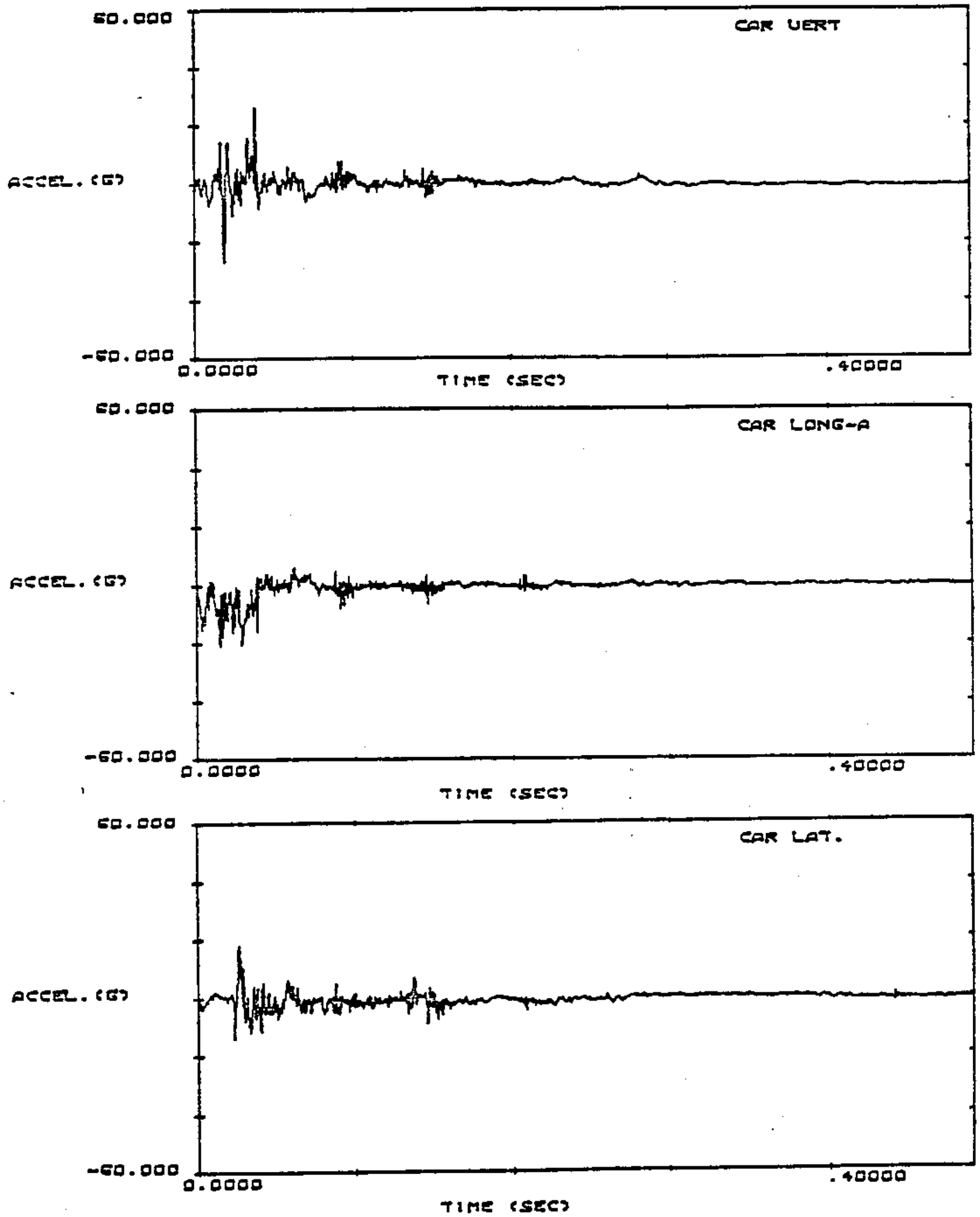


Figure C9

TEST NUMBER
403.00
LIGHTWEIGHT
LIGHTING
STANDARD
JULY 20 1983

CAR WEIGHT
(POUNDS)-
1850.0
MASS(SLUGS)-
5.7453E-02

KINETIC
ENERGY (KE)
EQUALS 1/2
MASS TIMES
THE SQUARE
OF THE VEL.

AT IMPACT
VEL. (FPS)-
86.643
VEL. (MPH)-
59.075
K.E. (FT-K)-
215.65

DISSIPATED
KE (AT END
OF ANALYSIS)
70.782

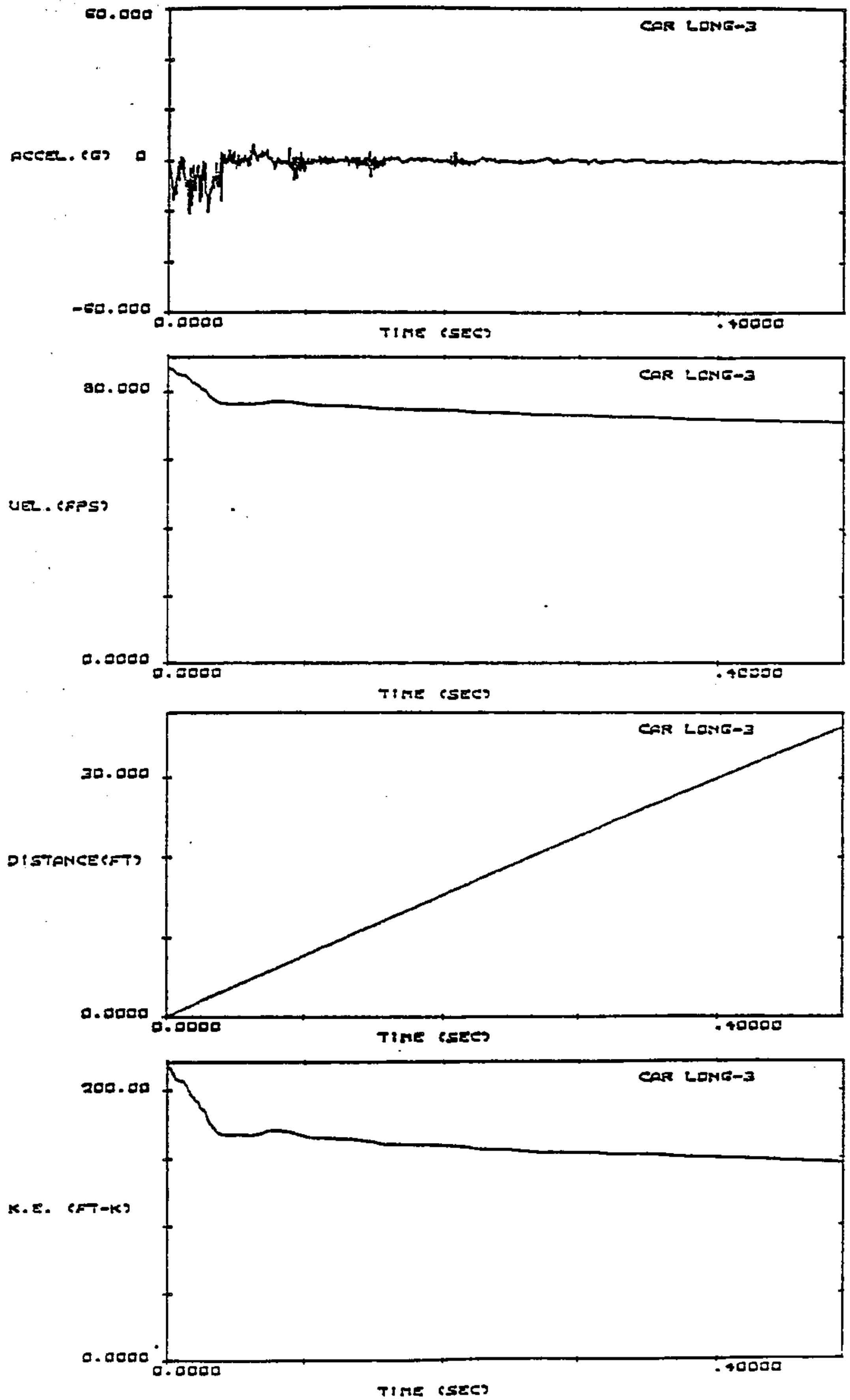


Figure C10

TEST NUMBER
403.00
LIGHTWEIGHT
LIGHTING
STANDARD
JULY 20 1983

CAR IMPACT
VELOCITY
(FPS)-
86.643

AT CAR
DISTANCE(FT)
15.590
OCCUPANT
IMPACT
OCCURS

OCCUPANT
IMPACT
VELOCITY
(FPS)-
12.374
OCCURS AT
.20300
SEC. AFTER
CAR IMPACT

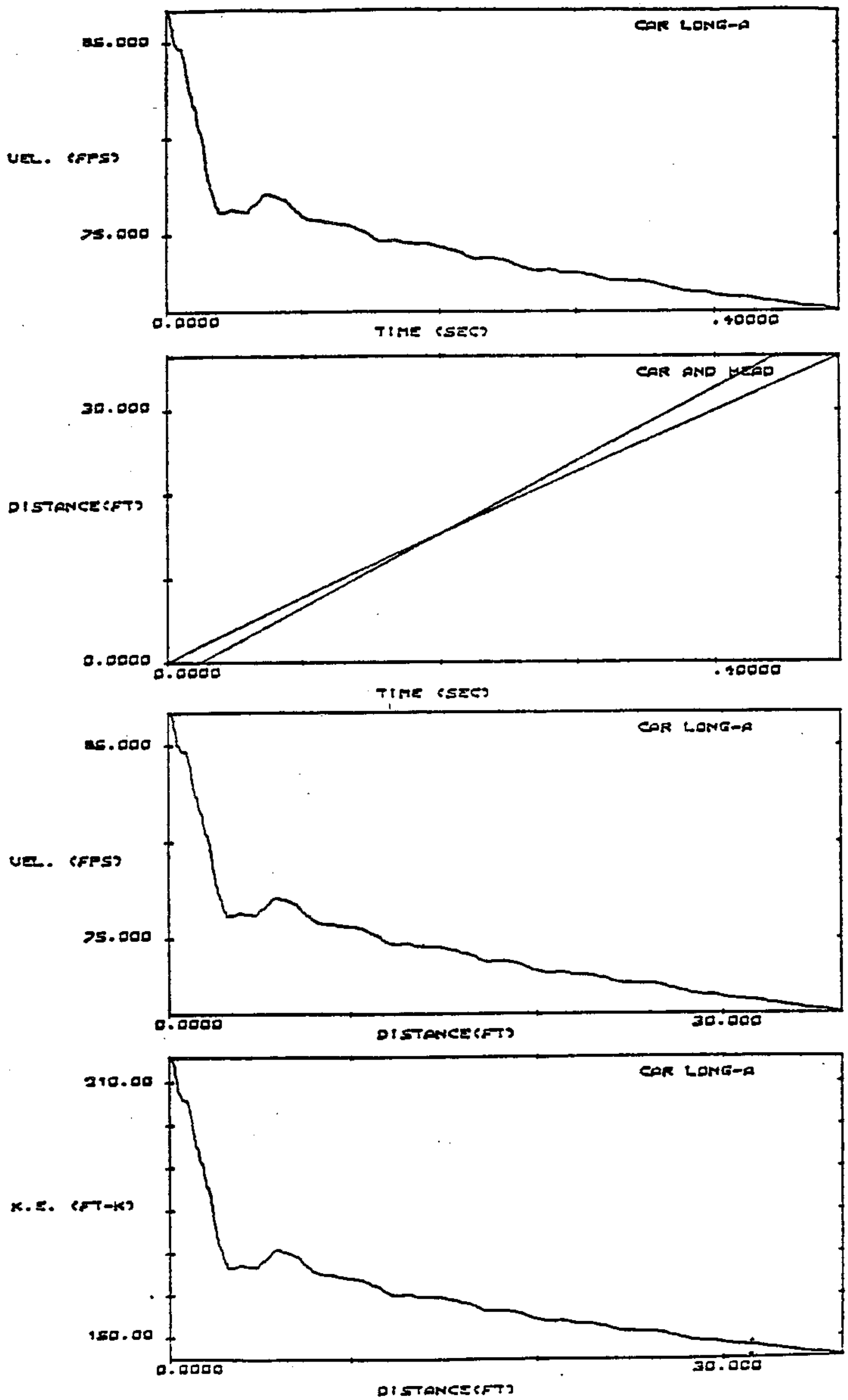


Figure C11

TEST NUMBER

403.00

LIGHTWEIGHT

LIGHTING

STANDARD

JULY 20 1983

MAXIMUM

50 MS AVER.

DUMMY HEAD

RESULTANT

ACCEL. (G)-

7.0279

FROM TIME(S)

.13200

TO TIME(S)

.18200

HEAD INJURY

CRITEREON-

8.0453

FROM TIME(S)

.13200

TO TIME(S)

.35850

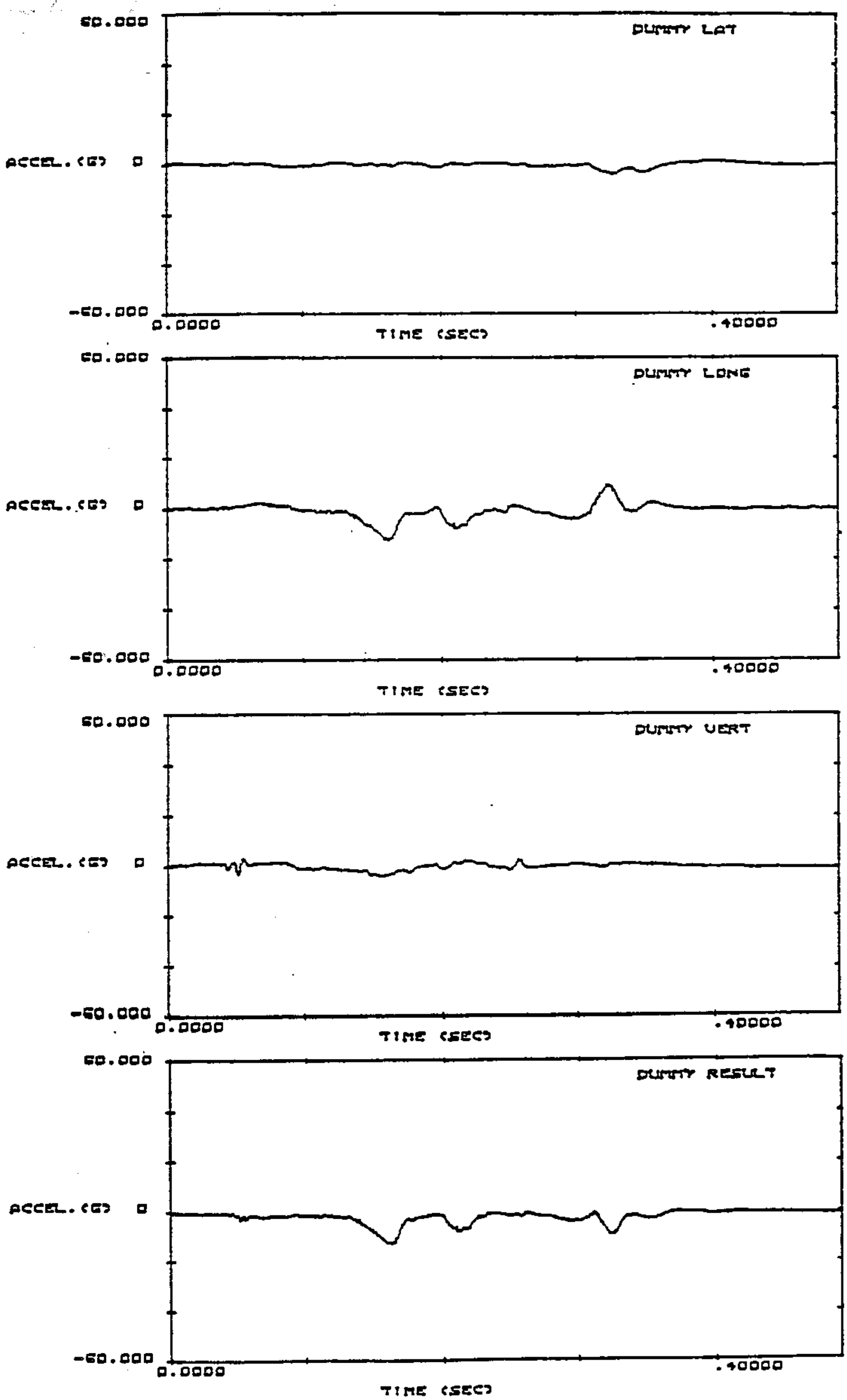


Figure C12

TEST NUMBER
404.00
CALTRANS
TYPE 31
LIGHTING
STANDARD
JULY 26 1984

MAX. 50 MS
AVER. ACCEL.
FOR CAR (G)-

VERTICAL---
-.80699
FROM TIME(S)
3.5000E-03

LONGITUDINAL
-5.4396
FROM TIME(S)
5.0000E-03

LATERAL
.86977
FROM TIME(S)
6.2000E-02

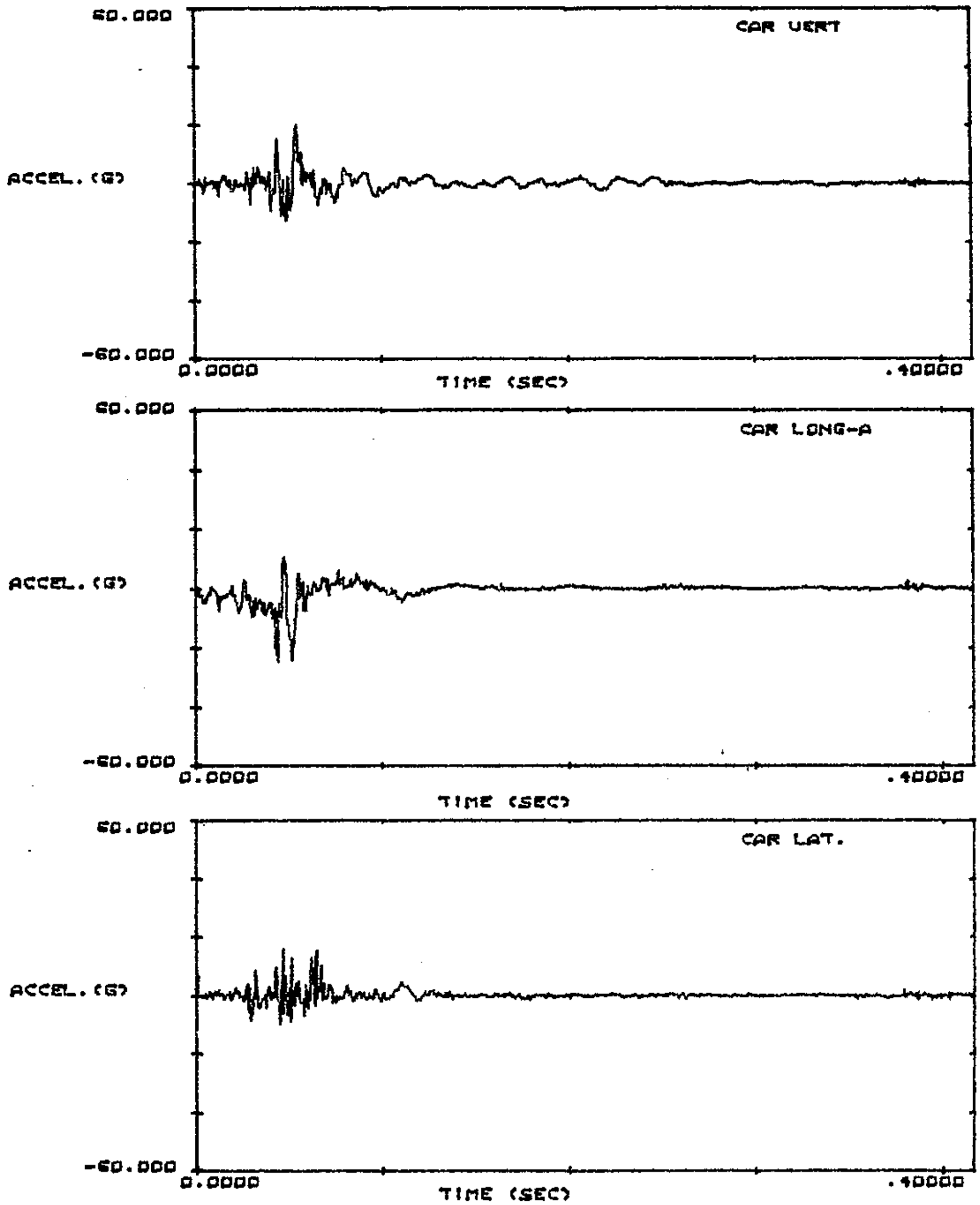


Figure C13

TEST NUMBER
404.00
CALTRANS
TYPE 31
LIGHTING STD
JULY 26 1984

CAR WEIGHT
(POUNDS)-
1865.0
MASS(SLUGS)-
5.7919E-02

KINETIC
ENERGY (KE)
EQUALS 1/2
MASS TIMES
THE SQUARE
OF THE VEL.

AT IMPACT
VEL. (FPS)-
29.197
VEL. (MPH)-
19.907
K.E. (FT-K)-
24.687

DISSIPATED
KE (AT END
OF ANALYSIS)
13.402

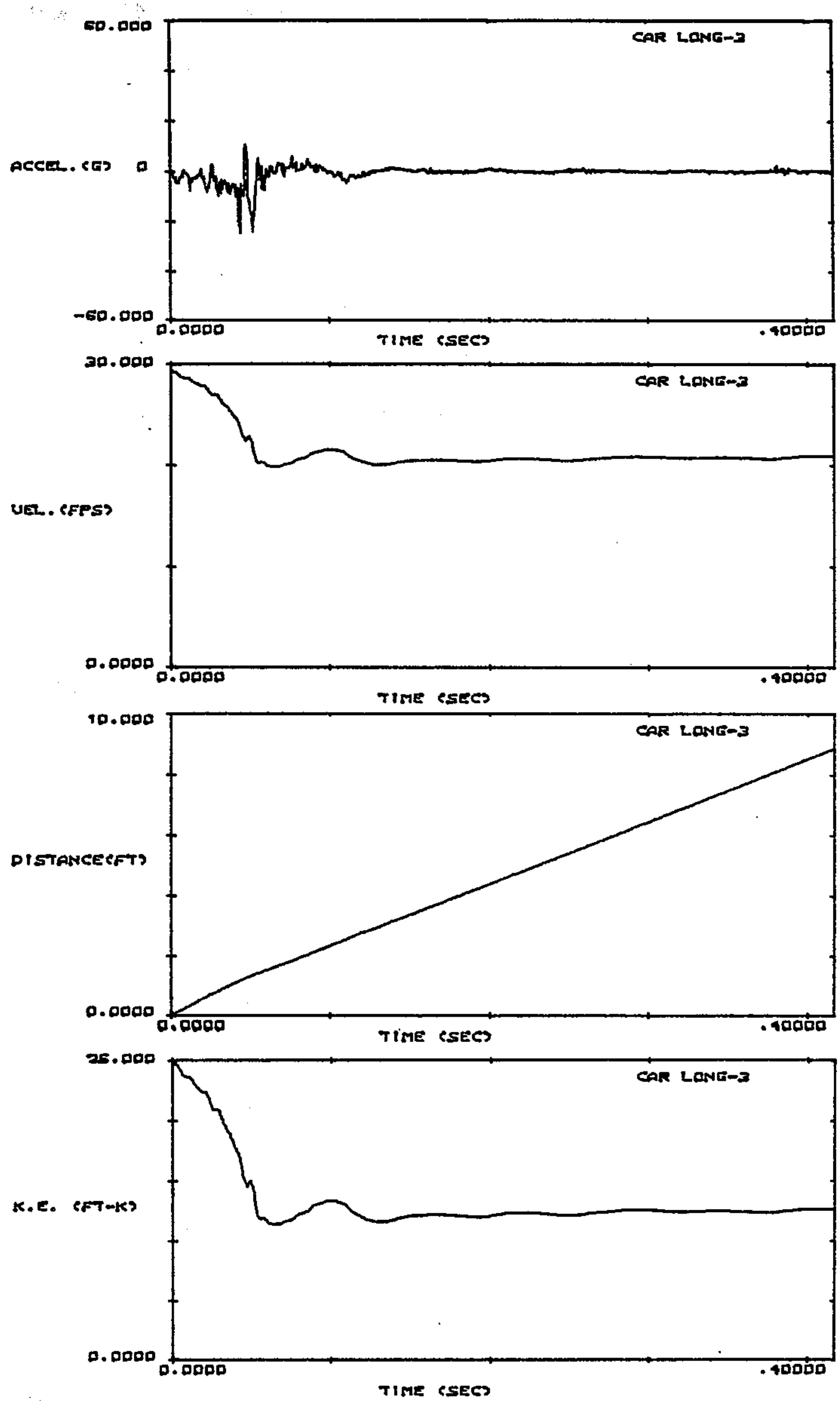


Figure C14

TEST NUMBER
404.00
CALTRANS
TYPE 31
LIGHTING
STANDARD
JULY 26 1984

CAR IMPACT
VELOCITY
(FPS)-
29.197

AT CAR
DISTANCE(FT)
5.7659
OCCUPANT
IMPACT
OCCURS

OCCUPANT
IMPACT
VELOCITY
(FPS)-
8.5356
OCCURS AT
.26600
SEC. AFTER
CAR IMPACT

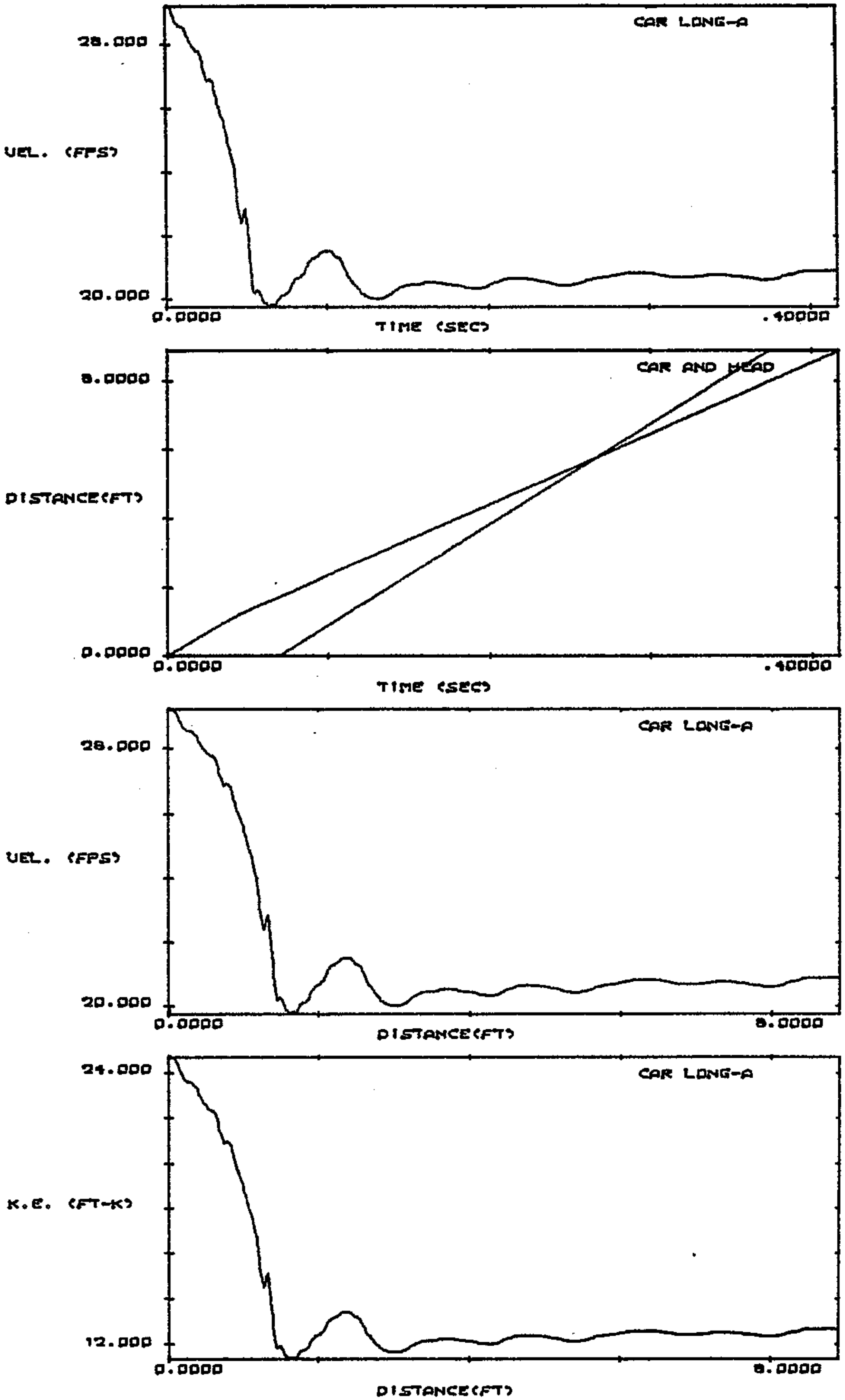


Figure C15

TEST NUMBER
404.00
CALTRANS
TYPE 31
LIGHTING
STANDARD

JULY 26 1984

MAXIMUM
50 MS AVER.
DUMMY HEAD
RESULTANT
ACCEL. (G)-
8.2241
FROM TIME(S)
.16000
TO TIME(S)
.21000

HEAD INJURY
CRITEREON-
10.034
FROM TIME(S)
.13400
TO TIME(S)
.23950

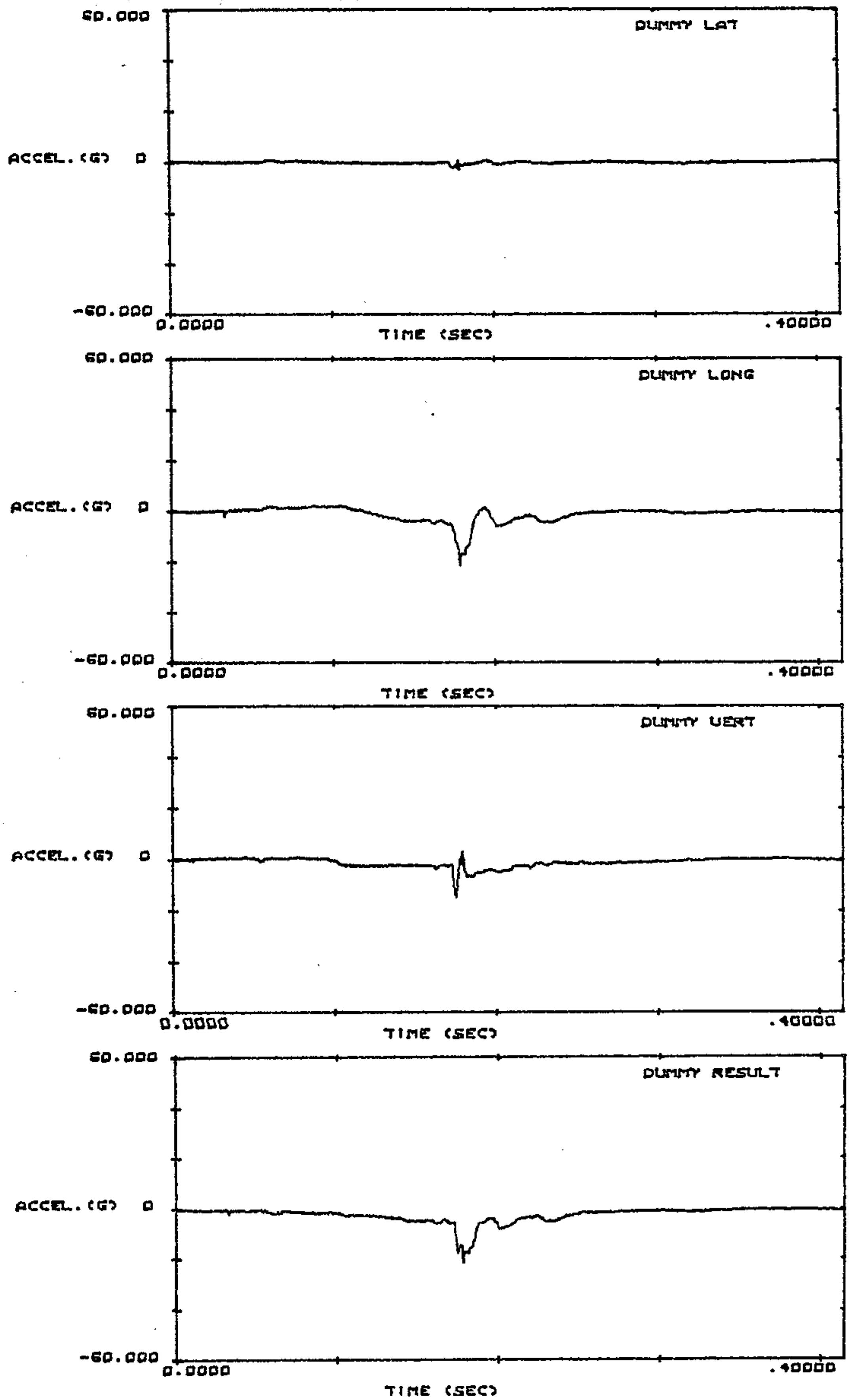


Figure C16

TEST NUMBER

405.00

CALTRANS

TYPE 31

LIGHTING

STANDARD

MAY 23 1985

MAX. 50 MS

AVER. ACCEL.

FOR CAR (G)-

VERTICAL---

-1.3685

FROM TIME(S)

5.1000E-02

LONGITUDINAL

-7.2498

FROM TIME(S)

0.0000

LATERAL

-1.6418

FROM TIME(S)

3.1500E-02

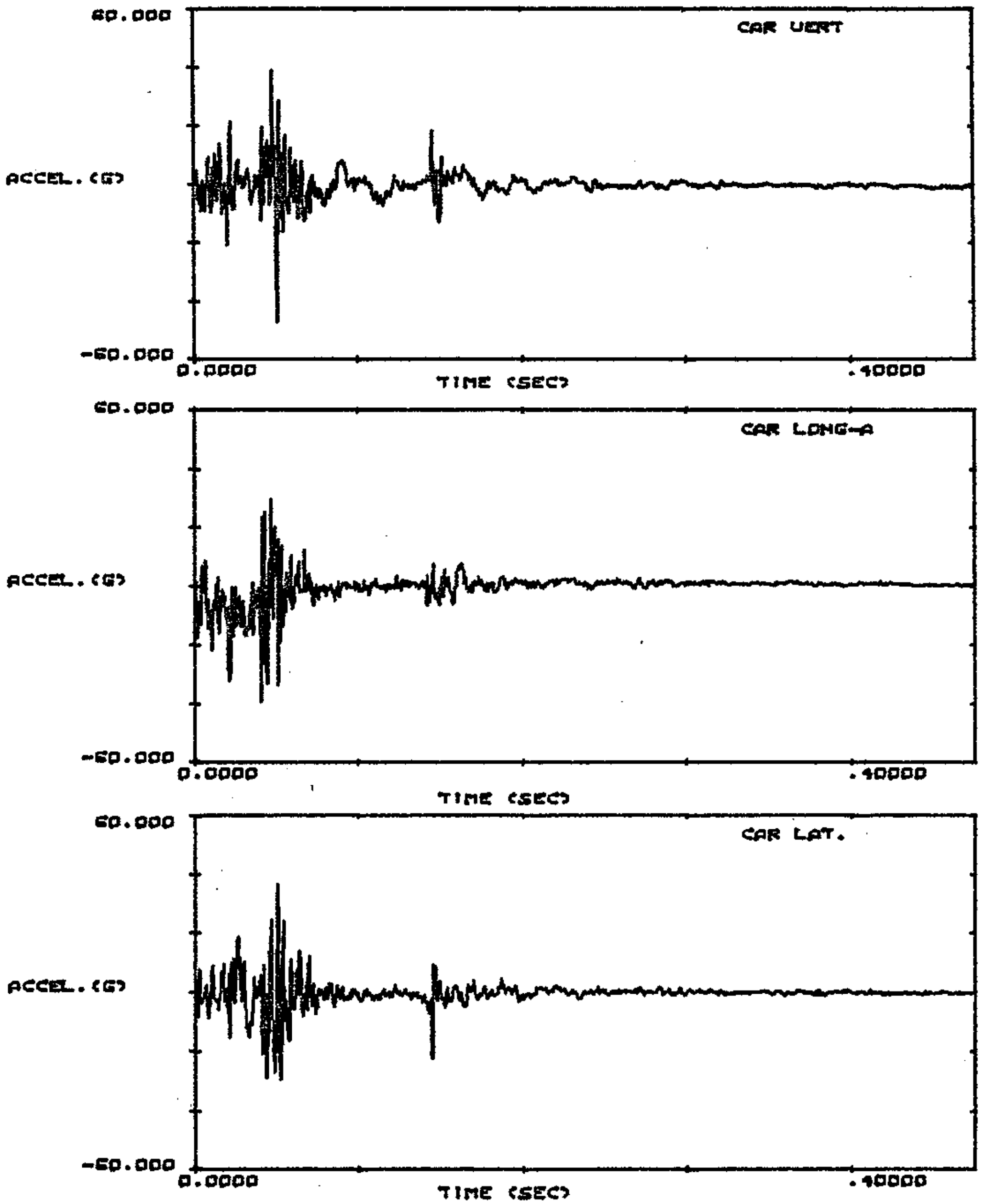


Figure C17

TEST NUMBER

405.00

CALTRANS

TYPE 31

LIGHTING

STANDARD

MAY 23 1985

CAR WEIGHT

(POUNDS)-

1885.0

MASS(SLUGS)-

5.8540E-02

KINETIC

ENERGY (KE)

EQUALS 1/2

MASS TIMES

THE SQUARE

OF THE VEL.

AT IMPACT

VEL. (FPS)-

79.053

VEL. (MPH)-

53.900

K.E. (FT-K)-

182.92

DISSIPATED

KE (AT END

OF ANALYSIS)

56.687

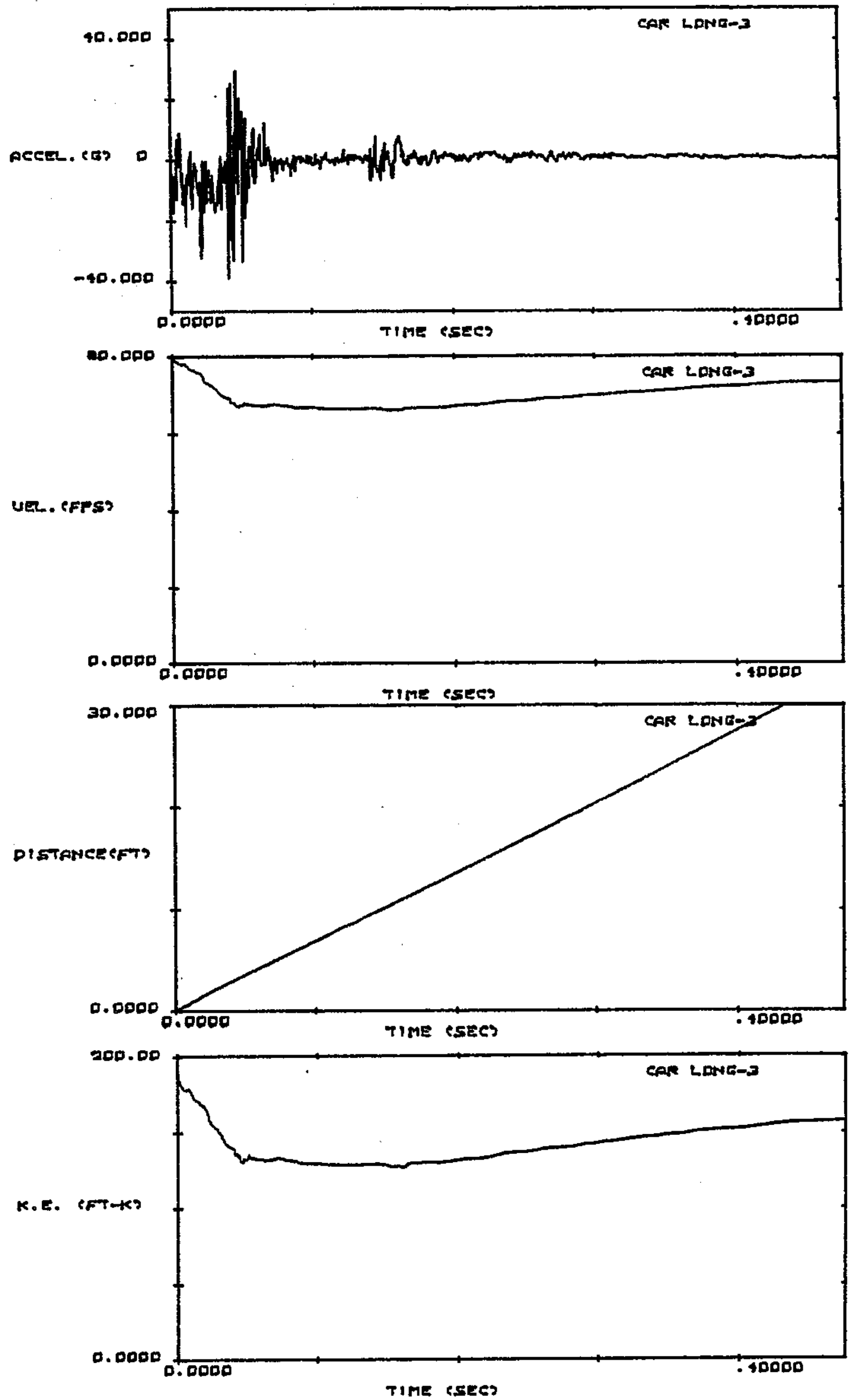


Figure C18

TEST NUMBER
405.00
CALTRANS
TYPE 31
LIGHTING
STANDARD

MAY 23 1985

CAR IMPACT
VELOCITY
(FPS)-
79.054

AT CAR
DISTANCE(FT)
12.707
OCCUPANT
IMPACT
OCCURS

OCCUPANT
IMPACT
VELOCITY
(FPS)-
12.417
OCCURS AT
.18600
SEC. AFTER
CAR IMPACT

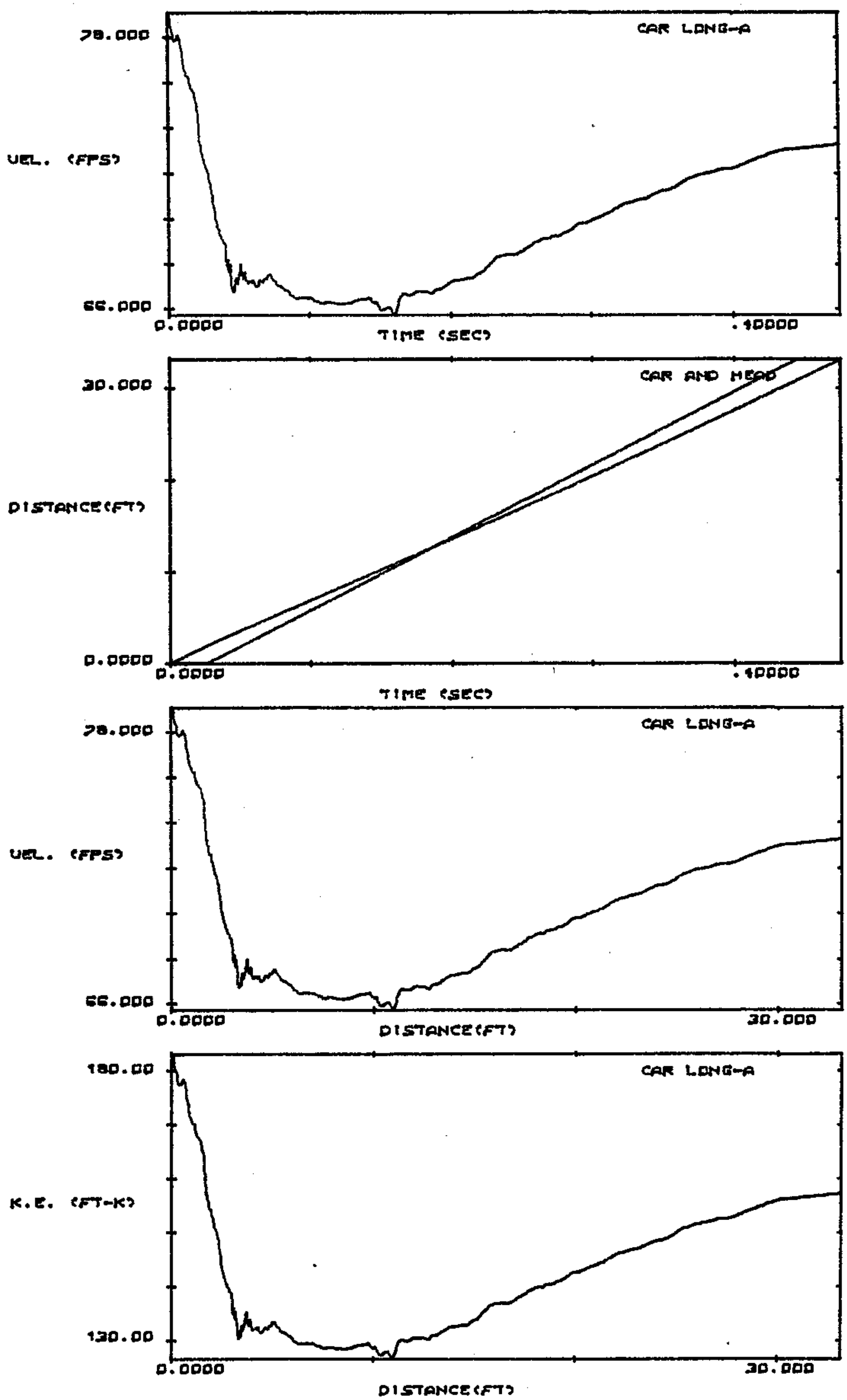


Figure C19

TEST NUMBER
405.00
CALTRANS
TYPE 31
LIGHTING
STANDARD

MAY 23 1985

MAXIMUM
50 MS AVER.
DUMMY HEAD
RESULTANT
ACCEL. (G)-
6.1079
FROM TIME(S)
.17750
TO TIME(S)
.22750

HEAD INJURY
CRITEREON-
8.0258
FROM TIME(S)
2.5500E-02
TO TIME(S)
.30000

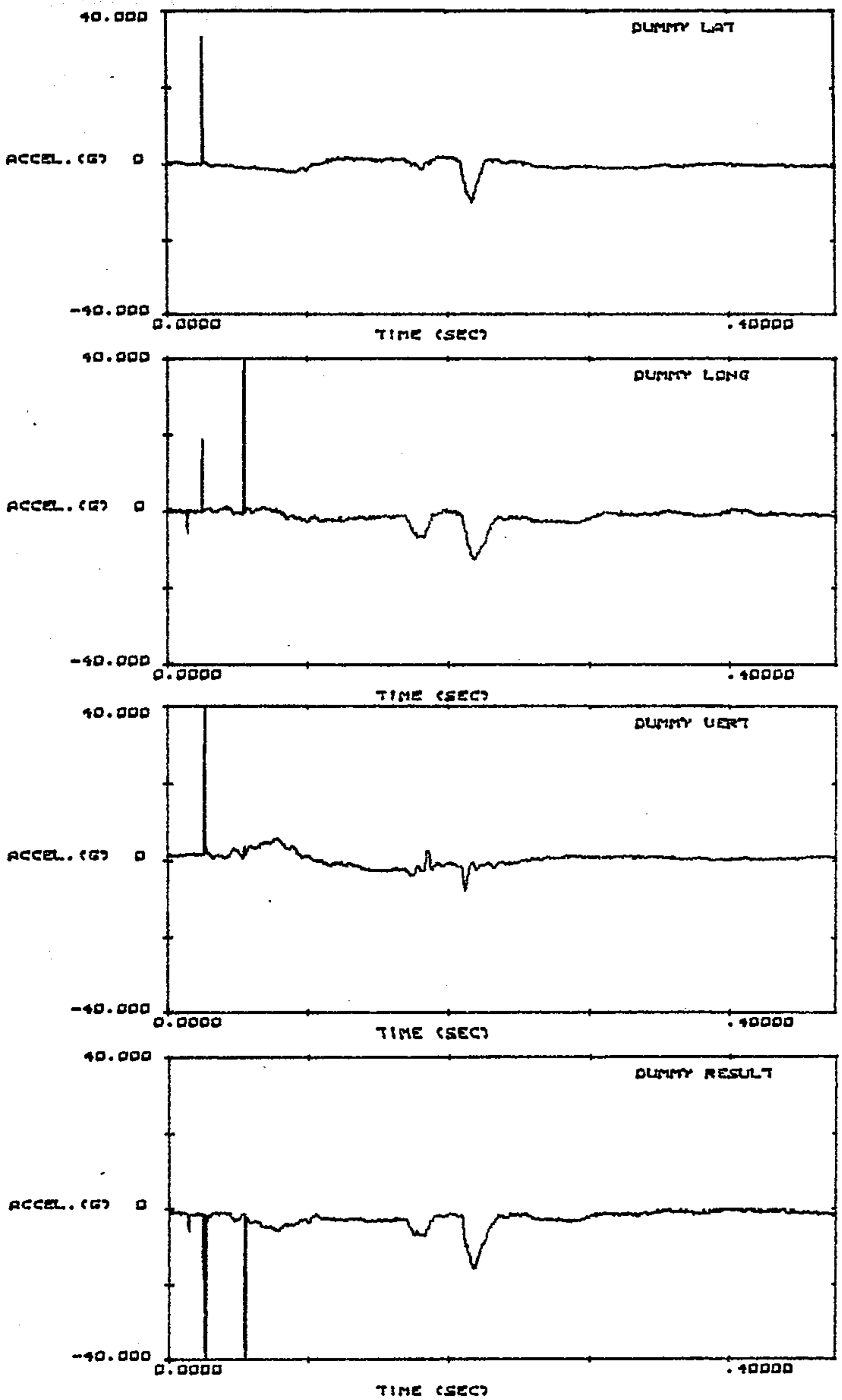


Figure C20

TEST NUMBER
406.00
STEEL POLE
LIGHT STD
WITH SLIP
BASE

MAY 8 1987

MAX. 50 MS
AVER. ACCEL.
FOR CAR (G)-

VERTICAL---
1.6410
FROM TIME(S)
7.5000E-03

LONGITUDINAL
-7.1550
FROM TIME(S)
0.0000

LATERAL
1.4897
FROM TIME(S)
3.1000E-02

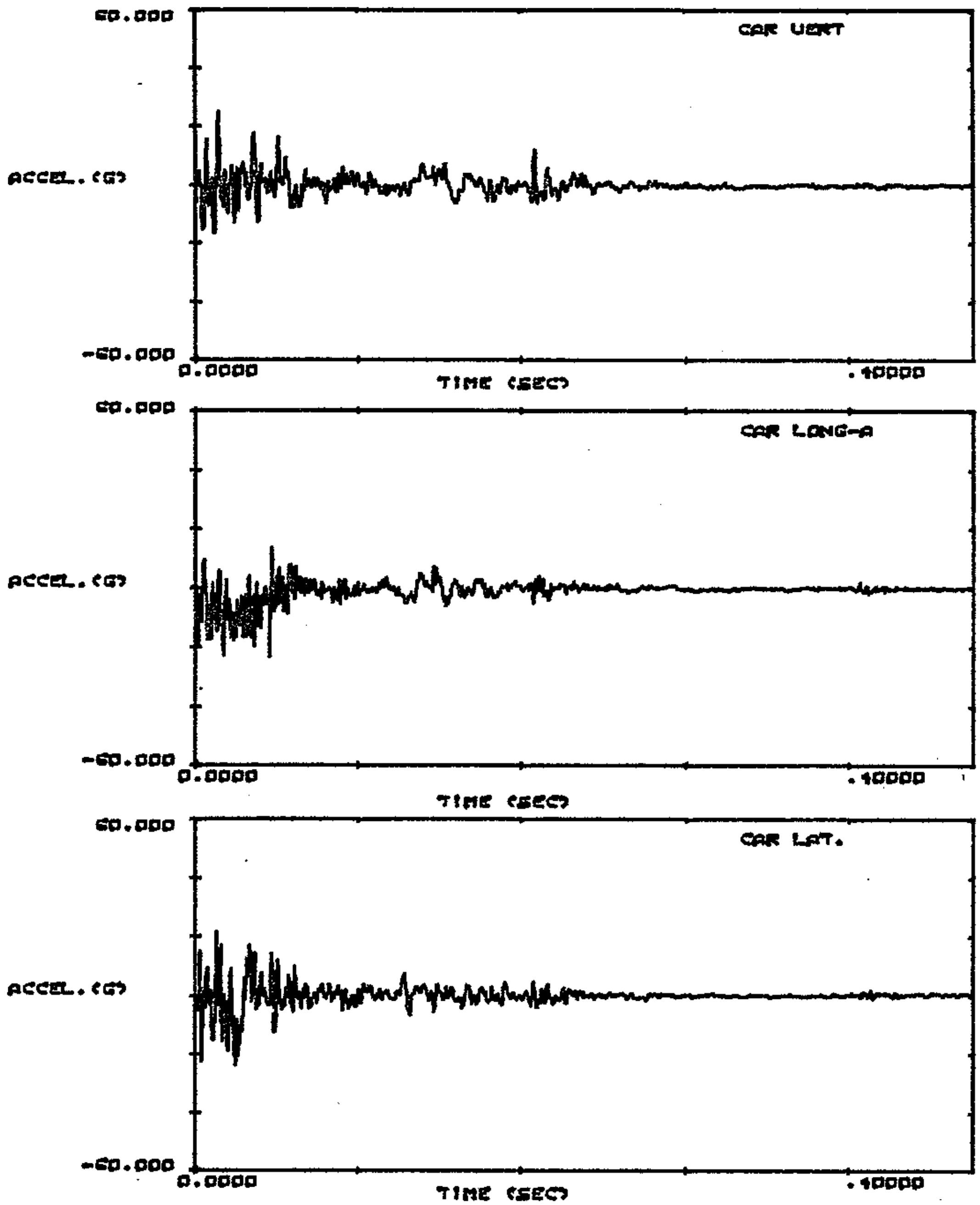


Figure C21

TEST NUMBER
406.00
STEEL POLE
LIGHT STD
WITH SLIP
BASE

MAY 8 1987

CAR WEIGHT
(POUNDS)-
1800.0
MASS(SLUGS)-
5.5901E-02

KINETIC
ENERGY (KE)
EQUALS 1/2
MASS TIMES
THE SQUARE
OF THE VEL.
AT IMPACT
VEL. (FPS)-
86.240
VEL. (MPH)-
58.800
K.E. (FT-K)-
207.88
DISSIPATED
KE (AT END
OF ANALYSIS)
64.900

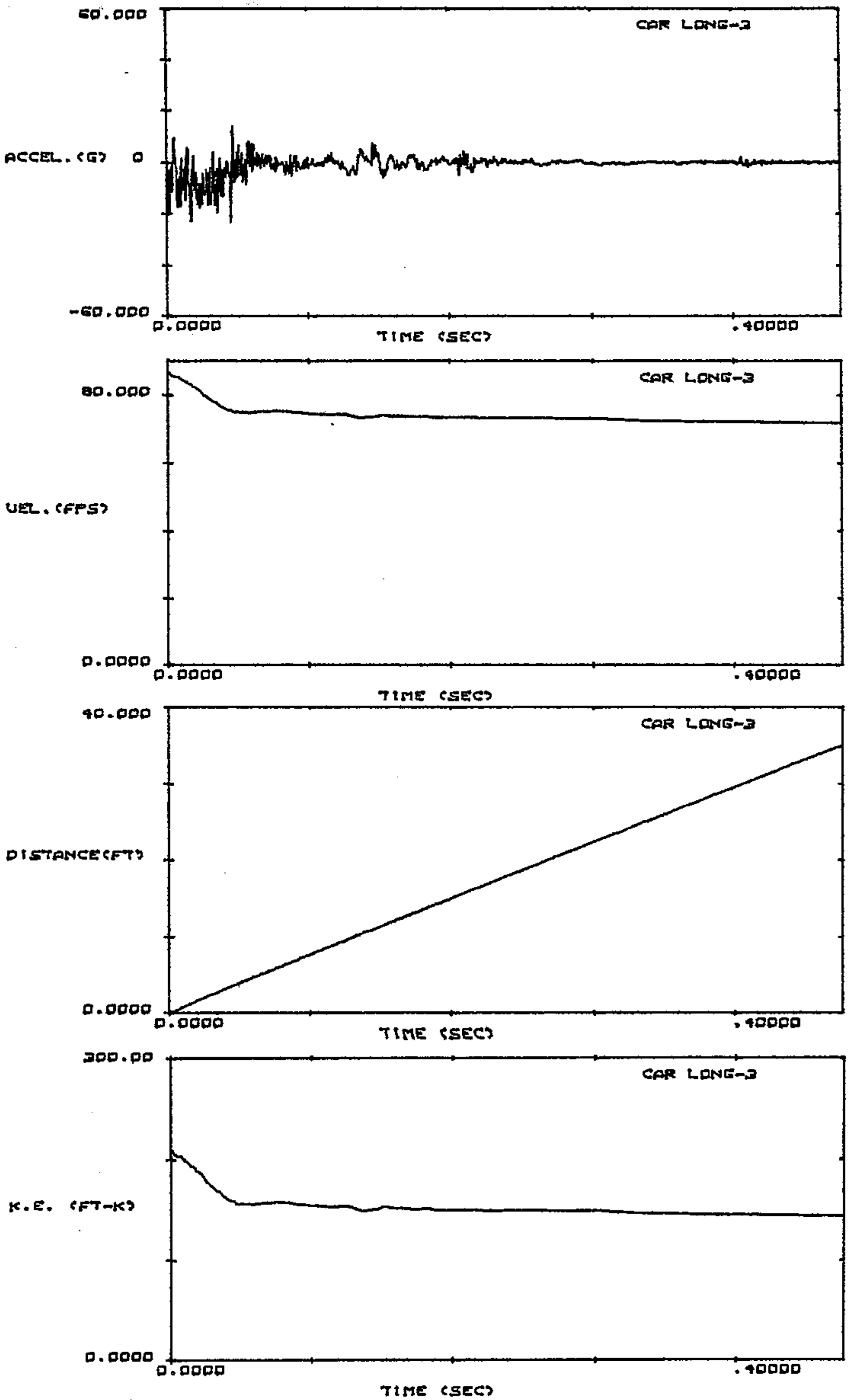


Figure C22

TEST NUMBER
406.00

STEEL POLE
LIGHT STD
WITH SLIP
BASE
MAY 8 1987

CAR IMPACT
VELOCITY
(FPS)-
86.240

AT CAR
DISTANCE(FT)
14.384
OCCUPANT
IMPACT
OCCURS

OCCUPANT
IMPACT
VELOCITY
(FPS)-
13.095
OCCURS AT
.19000
SEC. AFTER
CAR IMPACT

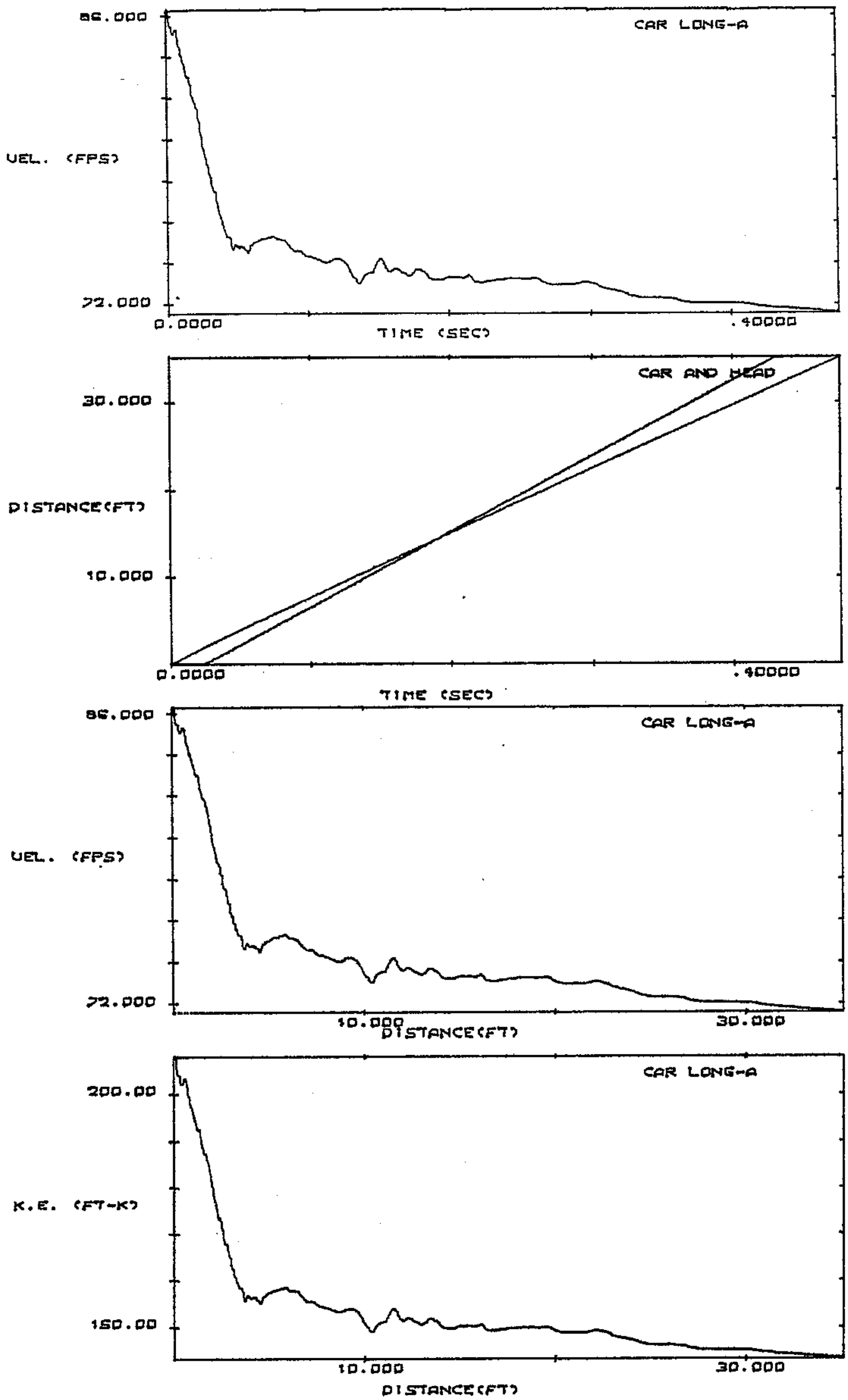


Figure C23

TEST NUMBER
406.00
STEEL POLE
LIGHT STD
WITH SLIP
BASE

MAY 8 1987

MAXIMUM
50 MS AVER.
DUMMY HEAD
RESULTANT
ACCEL. (G)-
6.4010
FROM TIME(S)
.16900
TO TIME(S)
.21900

HEAD INJURY
CRITEREON-
7.0658
FROM TIME(S)
.14250
TO TIME(S)
.22200

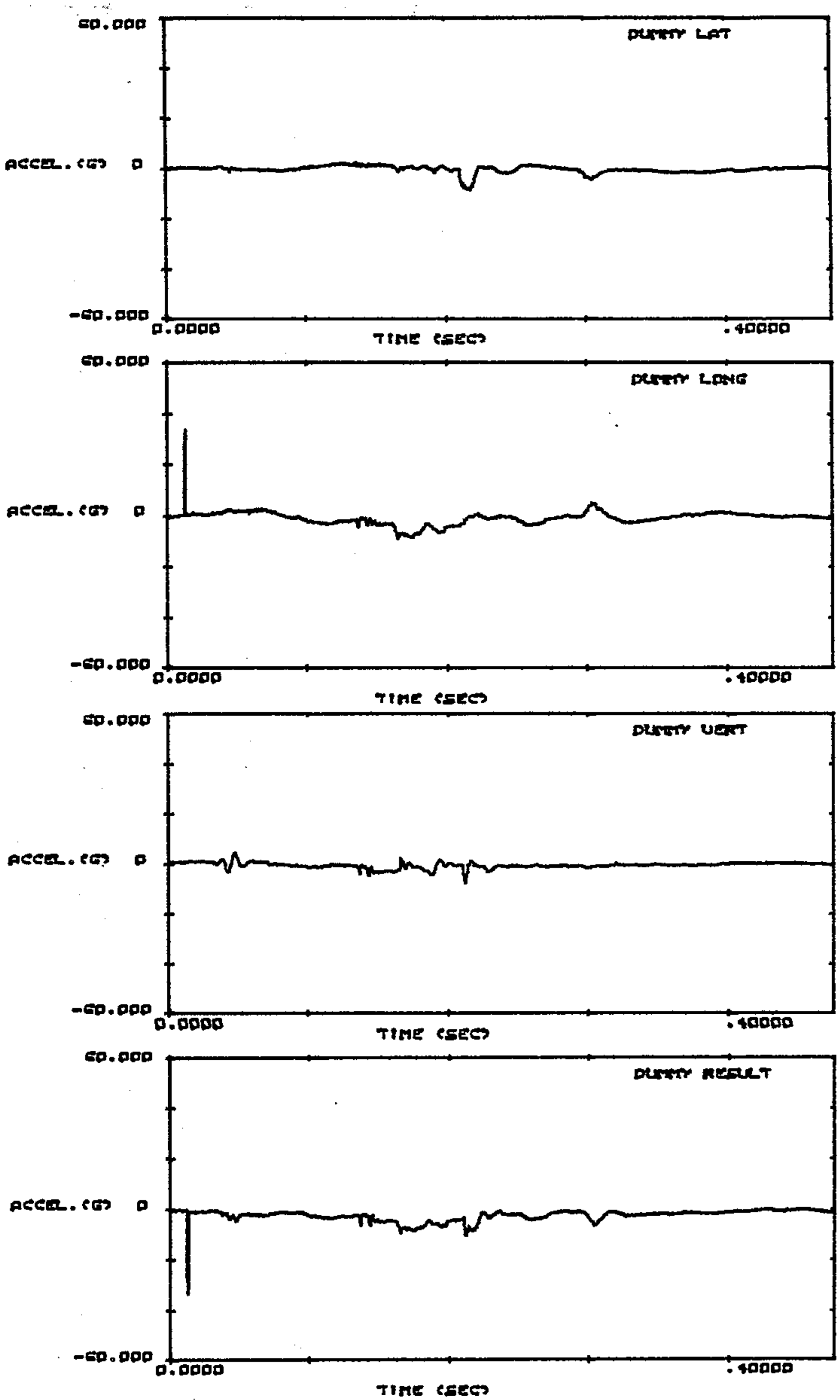


Figure C24

TEST NUMBER
407.00

STEEL POLE
LIGHT STD
WITH SLIP
BASE

JUNE 23 1987

MAX. 50 MS
AVER. ACCEL.
FOR CAR (G)-

VERTICAL
1.6252
FROM TIME(S)
4.5500E-02

LONGITUDINAL
-5.7315
FROM TIME(S)
2.0000E-03

LATERAL
-.54407
FROM TIME(S)
5.3500E-02

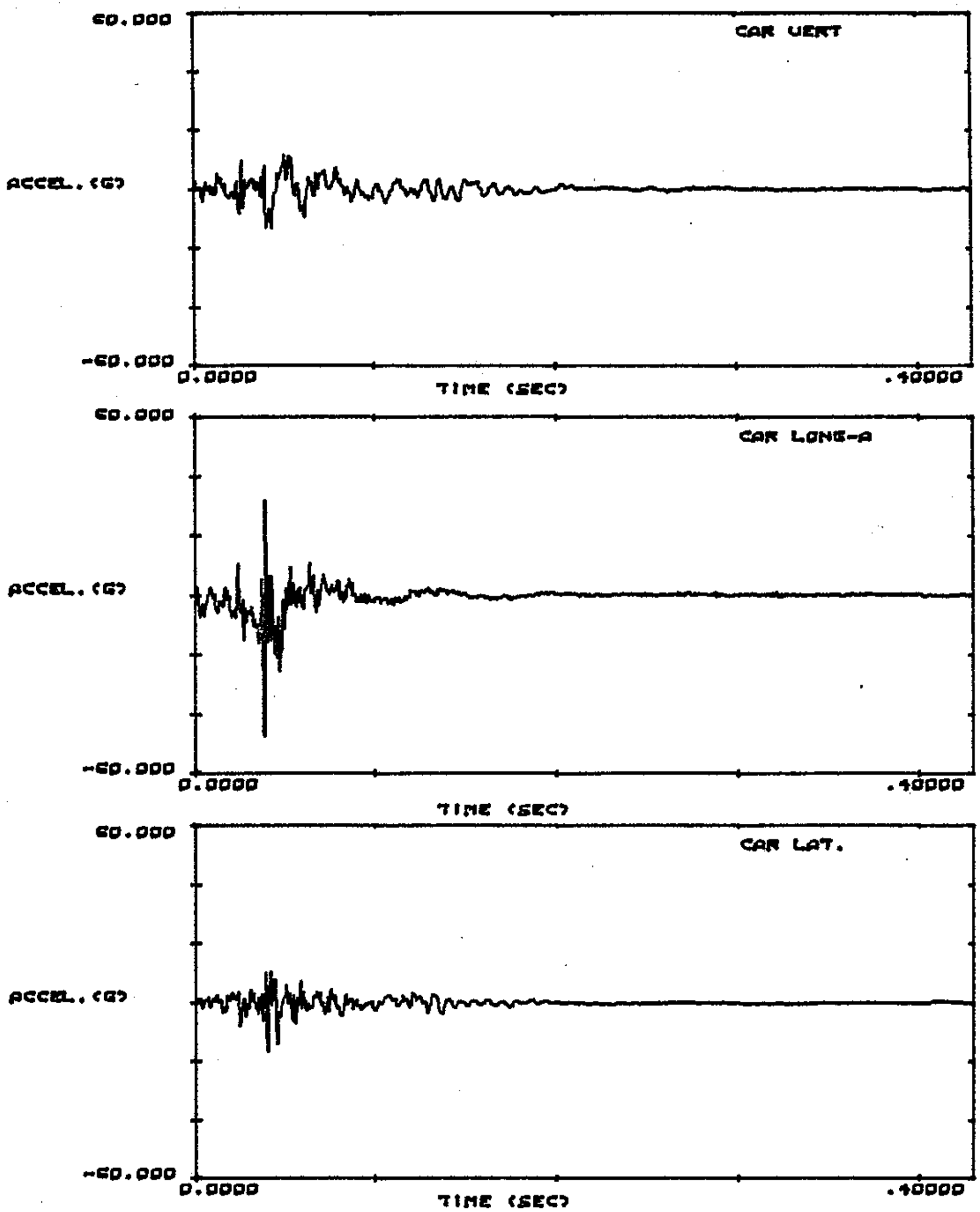


Figure C25

TEST NUMBER
407.00
STEEL POLE
LIGHT STD
WITH SLIP
BASE

JUNE 23 1987

CAR WEIGHT
(POUNDS)-
1870.0
MASS(SLUGS)-
5.8075E-02

KINETIC
ENERGY (KE)
EQUALS 1/2
MASS TIMES
THE SQUARE
OF THE VEL.
AT IMPACT
VEL. (FPS)-
34.760
VEL. (MPH)-
23.700
K.E. (FT-K)-
35.085
DISSIPATED
KE (AT END
OF ANALYSIS)
16.191

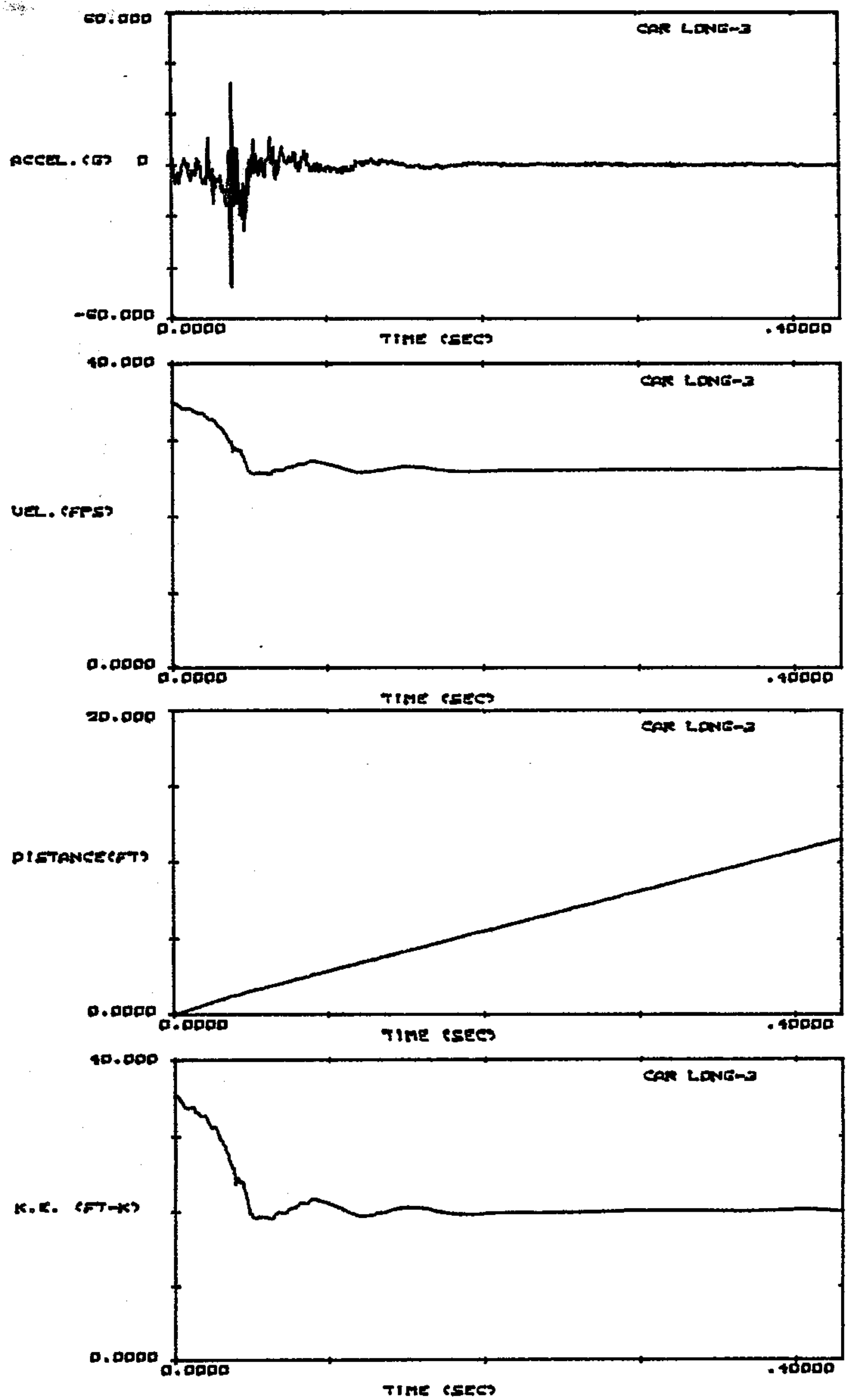


Figure C26

TEST NUMBER
407.00

STEEL POLE
LIGHT STD
WITH SLIP
BASE

JUNE 23 1987

CAR IMPACT
VELOCITY
(FPS)-
34.759

AT CAR
DISTANCE(FT)
7.3146
OCCUPANT
IMPACT
OCCURS

OCCUPANT
IMPACT
VELOCITY
(FPS)-
8.5847
OCCURS AT
.26800
SEC. AFTER
CAR IMPACT

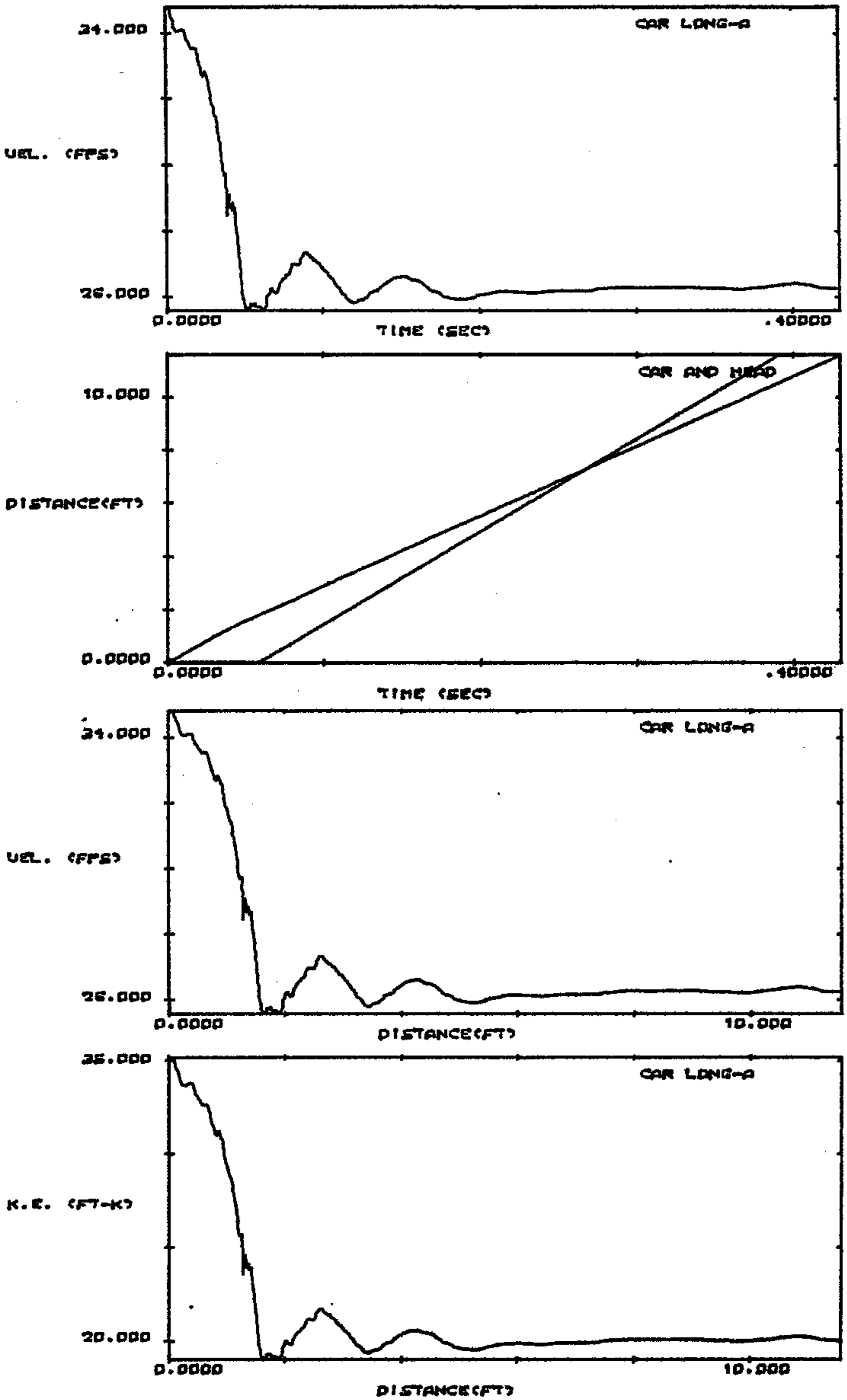


Figure C27

TEST NUMBER

407.00

STEEL POLE

LIGHT STD

WITH SLIP

BASE

JUNE 23 1987

MAXIMUM

50 MS AVER.

DUMMY HEAD

RESULTANT

ACCEL. (G)-

3.6364

FROM TIME(S)

.12150

TO TIME(S)

.17150

HEAD INJURY

CRITEREON-

2.0455

FROM TIME(S)

4.8000E-02

TO TIME(S)

.39150

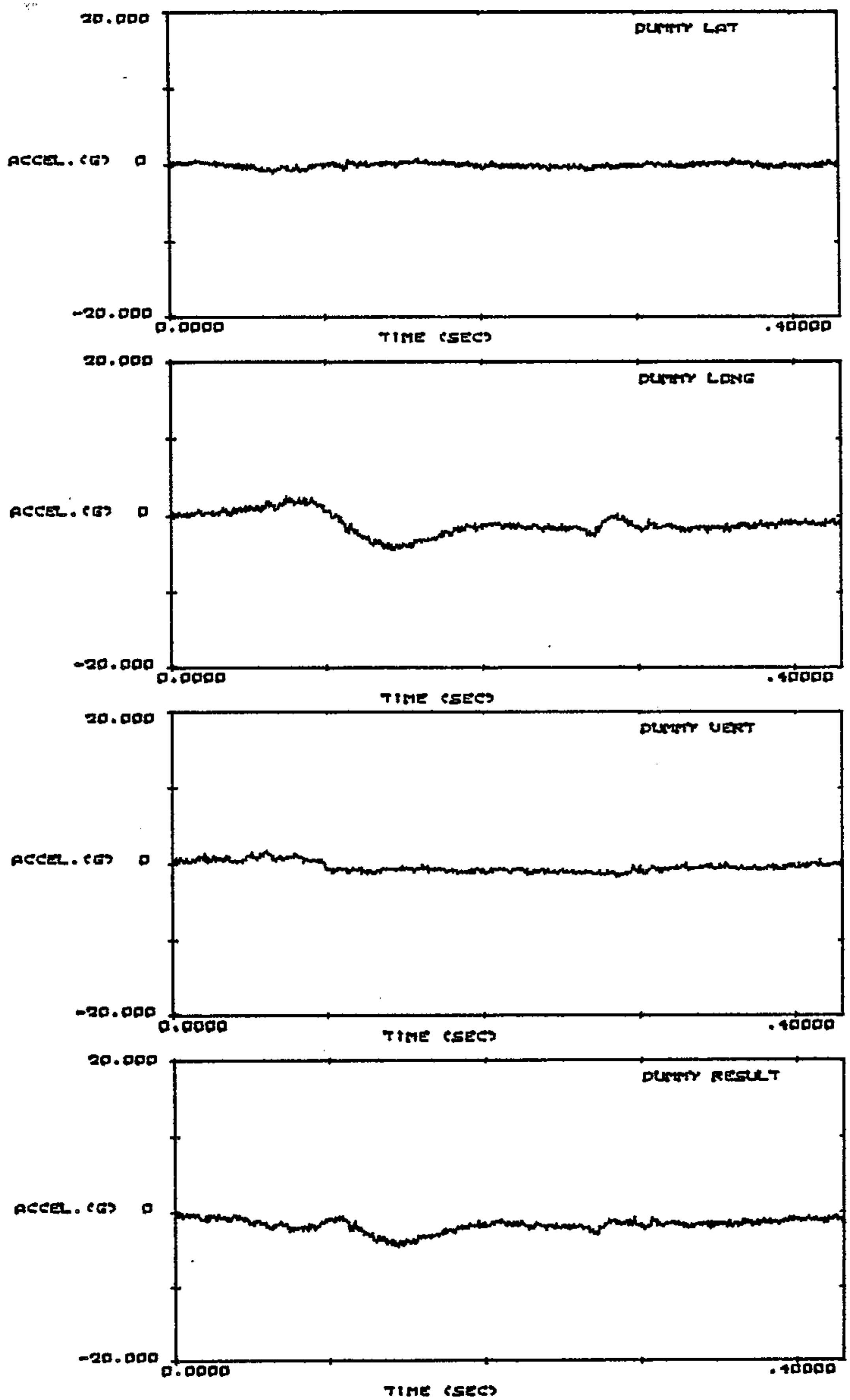


Figure C28

Appendix D: Data Summary of Crash Tests on Breakaway Lighting Standards (Slip Base and Aluminum Couplings)

Table D1

Data Summary of Crash Tests on Breakaway Lighting Standards

Test I.D.			Lighting Standards				Breakaway Device	Vehicle		
Ref. No.	Test No.	Test Date	Type	Height of Pole * (feet)	Length of Mast Arm (feet)	Total Weight (lbs)	Type	Year/Type	Weight Without Dummy, lbs	Dummy Weight lbs
3, TTI	3537-1	1977	Steel	45(50)	7.5	676.8	Alu. Coup	73/Vega	2290	
11, ENSCO	502	1984	Aluminum	40	None	282	Alu. Coup	Bogie	1850	
11, ENSCO	505	1984	Aluminum	40	None	282	Alu. Coup	Bogie	1905	
11, ENSCO	508	1984	Aluminum	40	None	273	Alu. Coup	Bogie	1850	
CALTR	401	1982	Aluminum	35	20	394	Alu. Coup	79/Honda	1890	165
CALTR	402	1982	Aluminum	35	20	394	Alu. Coup	79/Honda	1850	165
CALTR	403	1983	Mod. 31	35	20	651	Alu. Coup	79/Honda	1870	165
10, AGI	87F054	1987	Steel	(55)	16	995	Alu. Coup	Bogie	1850	
10, AGI	87F055	1987	Steel	(55)	16	995	Alu. Coup	Bogie	1850	
10, AGI	87F073	1987	Steel	(53)	15	523	Alu. Coup	Bogie	1850	
10, AGI	87F074	1987	Steel	(53)	15	523	Alu. Coup	Bogie	1850	
10, AGI	87F075	1987	Steel	(45)	10	523	Alu. Coup	Bogie	1850	
10, AGI	87F076	1987	Steel	(45)	10	523	Alu. Coup	Bogie	1850	

Table D1

Data Summary of Crash Tests on Breakaway Lighting Standards

Test I.D.	Test Characteristics			Test Results					
Test No.	Point of Impact	Desired Impact Velocity	Actual Velocity F/S.T.,mph	Velocity Change, mph		Momtm Change dM (lb-Sec.)	Head Injury Criteria	Max. Crush of Bumper,in.	Stub Height (in.)
				Ve-F/S.T.	dV-F/Acc.				
3537-1	Center	20	20/20.6	/15.4	/5.2	539		18	
502	15in off cen	20	/20.8	7.9/9.7	11.1/10	888		18.4	
505	Center	20	/20.2	4.8/4.6	15.6/13.3	1160		19.6	
508	15in off cen	60	58.9/59.1	48.7/49.9	10.2/8.9	793		25.5	
401	12in RCL	60	58.6	/52.2	/6.4	597	1.8	11.25	3.5
402	Center	20	19.6	/12.5	/7.1	651	0.8	11.25	3.5
403	9.5 RCL	60	59.1	/50.7	/8.4	781	8	14.25	3.5
87F054		20			11.9	1005			5
87F055		60			9.4	793			5
87F073		20			7.6	643			2.5
87F074		60			6	506			2.5
87075		20			11.4	959			2.5
87076		60			8	672			2.5

Table D1

Data Summary of Crash Tests on Breakaway Lighting Standards

Test I.D.			Lighting Standards				Breakaway Device	Vehicle		
Ref. No.	Test No.	Test Date	Type	Height of Pole * (feet)	Length of Mast Arm (feet)	Total Weight (lbs)	Type	Year/Type	Weight Without Dummy, lbs	Dummy Weight (lbs)
22, TTI	1075-S2	1968	Steel	40 (45)	10		Slip Base	59/Ford	3400	
22, TTI	1075-S3	1968	Steel	40 (45)	10		Slip Base	57/Ford	3500	
5, TTI	538-10	1968	Steel	35 (40)	15		Slip Base	58/Ford	3340	
6, TTI	8	1969	Steel	35 (40)			Slip Base	58/Ford	3640	
15, CALTR	195	1968	St. CA-XV	28.5 (30)	12		Slip Base	66/Dodge	4540	
15, CALTR	196	1968	St. CA-XV	28.5 (30)	12		Slip Base	66/Dodge	4540	
16, TTI	C7	1971	Steel	40			Slip Base		2290	
16, TTI	C8	1971	Steel	40			Slip Base		2310	
2, TTI	LS-9	1971	Steel	38 (45)			Slip Base	63/Chev	3710	
14, CALTR	311	1975	St. CA-31	35 (40)	30	992	Slip Base	71/Ford	2100	165
14, CALTR	312	1975	St. CA-31	35 (40)	30	992	Slip Base	71/Ford	2100	165
12, ENSCO	1469-1A81	1981	Steel	34	None	1003	Slip Base	71/Vega	2264	None
12, ENSCO	1469-2A82	1982	Steel	34	None	1003	Slip Base	76/Rabbit	1813	Two, 327
12, ENSCO	1469-3A82	1982	Steel	34	None	1002.7	Slip Base	76/Rabbit	1809	Two, 344
11, ENSCO	501	1984	Steel	35	None	1003	Slip Base	Bogie	1850	None
11, ENSCO	504	1984	Steel	28	None	292	Slip Base	Bogie	1905	None
11, ENSCO	509	1984	Steel	28	None	292	Slip Base	Bogie	1850	None
11, ENSCO	515	1985	Steel	28	None	292	Slip Base	Bogie	1905	None

Table D1

Data Summary of Crash Tests on Breakaway Lighting Standards

Test I.D.	Test Characteristics			Test Results					
Test No.	Point of Impact	Desired Impact Velocity	Actual Velocity F/S.T., mph	Velocity Change, mph		Momtm Change dM (lb-Sec.)	Head Injury Criteria	Max. Crush of Bumper, in.	Stub Height (in.)
				Ve-F/S.T.	dV-F/Acc.				
1075-52	Left H.L.	40	38.3	35.9	2.4	372			
1075-53	Center	40	35.7	34	1.7/1.7	271			
538-10	Center	30	27.6	23.4	4.2	636		9	
8		40	40.6	37.7	2.9	481		9	
195	Center	40	40.4	39	1.4	290		9	
196	Center	15	15.8	14.8	1	207		3	
C7	Center	20	19.4	13.8	5.6	580			
C8	Center	60	57.8	51.7	6.1	645			
LS-9		40	40.2	37.8	2.4	425		3.6	
311	Center	20	17.5	10.8	6.7	691		17	
312	Center	40	34.5	27.3	7.2	743		18.5	
1469-1A01	3.5in RCL	60	60.9	49.8	11.1	1141		21	
1469-2A02	14.25in LCL	56.7-64.6	61.6	52.2	9.4/1	972		18.5	
1469-3A02	12.25 LCL	18.7-21.2	19	/5.8	/13.2	1276		15.1	
501	15in Off Cen	20	/20.3	/8.9	11.4/10.6	925		21.3	
504	Center	20	/20.1	11.6/12.6	7.5/7.9	667		15	
509	15in Off Cen	60	58.8/59.7	54.5/53.1	4.3/5.9	474		22.6	
515	Center	60	58.4/59.2	53.6/53.3	4.9/5.7	499		22.25	

Table B1

Data Summary of Crash Tests on Breakaway Lighting Standards

Test I.D.			Lighting Standards				Breakaway Device	Vehicle		
Ref. No.	Test No.	Test Date	Type	Height of Pole * (feet)	Length of Mast Arm (feet)	Total Weight (lbs)	Type	Year/Type	Weight Without Dummy, lbs	Dummy Weight lbs
CALTR	404	1984	St. CA-31	35	20	883	Slip Base	79/Honda	1865	165
CALTR	405	1985	St. CA-31	35	20	883	Slip Base	79/Honda	1885	165
CALTR	406	1987	Mod. 31	35	20	627.4	Slip Base	79/Honda	1850	165
CALTR	407	1987	Mod. 31	35	20	639.4	Slip Base	79/Honda	1840	165
10, AGI	87F033	1987	Steel	49(56)	16	964	Slip Base	Bogie	1850	
10, AGI	87F034	1987	Steel	49(56)	16	964	Slip Base	Bogie	1850	
10, AGI	87F119	1987	Steel	(50)	15	626	Slip Base	Bogie	1850	
10, AGI	87F120	1987	Steel	(50)	15	626	Slip Base	Bogie	1850	

Table D1

Data Summary of Crash Tests on Breakaway Lighting Standards

Test I.D.	Test Characteristics			Test Results					
Test No.	Point of Impact	Desired Impact Velocity	Actual Velocity F/S.T., mph	Velocity Change, mph		Momtm Change dM (lb-Sec.)	Head Injury Criteria	Max. Crush of Bumper, in.	Stub Height (in.)
				Ve-F/S.T.	dV-F/Acc.				
404	Center	20	19.9	/14.1	/5.8	539	10	11	4.5
405	13.625 RCL	60	53.9	/45.4	/8.5	790	8	13-5/8	4.5
406	18.75 RCL	60	58.8	/49.9	/8.9	819	7.1	15-1/8	4.5
407	3 in RCL	20	23.7	/17.9	/5.8	534	2.1	12-7/8	4.5
87F033		20	19.8	10.3/10.2	9.5/10.2	862		18	3.5
87F034		60	58.3/58.7	50.3/48.8	8/8.7	730		23.7	3.5
87F119		20			10.5	885			3.8
87F120		60			6.6	557			3.8

Note:

Acc. = Accelerometer Data
Alu. Coup = Aluminum Coupling
Cen = Center = Center of Bumper
dM = Momentum Change
dV = Velocity Change (Maximum recommended by NCHRP Report 230 = 10.23 mph)
F = Film Data
H.L. = Head Light
LCL = Left of Center Line
RCL = Right of Center Line
Mod. = Modified
ST = Speed Trap Data
St. = Standard
Ve = Exit Velocity

Appendix E: Standard Special Provisions for Aluminum Couplings

September 9, 1988
(Previously revised 5/18/84)

STANDARD SPECIAL PROVISION

86-2.04 Breakaway Supports for Lighting Standards

Breakaway supports shall conform to the details shown on the plans and the provisions in Section 86, "Signals and Lighting", of the Caltrans Standard Specifications and these special provisions.

Aluminum couplings used as breakaway supports shall conform to the provisions of "AASHTO Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals". In addition, the couplings shall be capable of resisting the following test loads:

Type of Test		Acceptable Load Range
Restrained shear		3,600 lbs minimum
		5,500 lbs maximum
Axial tensile		24,000 lbs minimum
	No. of Cycles	Load Range
Cyclic	2 million	+6.5 kips to +12 kips
	2 million	-2.7 kips to +7.5 kips

Stainless steel or galvanized steel coupling studs may be used. Nuts for use on stainless steel studs may be grade A hex nuts suitable for use on grade A fasteners complying with requirements in the ASTM A307 specification. Thread tolerances for such nuts used on stainless steel studs shall conform to ANSI Standard B1.1, Class 2B tolerance.

The pitch diameter of female threads in the base of aluminum support couplings may be tapped over ANSI Standard B1.1, Class 2B tolerance according to allowances in Section 75-1.05.

The lot number and date of manufacturer shall be legibly printed on each coupling by die stamping or with indelible ink. Such identification shall be traceable back to the fabrication source and the manufacturer's quality control records.

A "Certificate of Compliance" accompanied by a certified test report shall be furnished for each lot of couplings in accordance with the provisions in Section 6-1.07, "Certificates of Compliance".

In addition, nine samples of the fabricated couplings will be furnished from each lot of 100 couplings or less for destructive testing by the Engineer. Samples will be selected at random from stock at the jobsite or at a location acceptable to the Engineer and the manufacturer. Three restrained shear tests (requiring 2 couplings each) and three axial load tests will be conducted. If any of the test results fail to meet the above test load requirements, the entire lot may be rejected, or a new sample and retest may be allowed at the discretion of the Engineer.

Manufacturers of die cast aluminum couplings shall also have ample radiographic inspections performed by certified NDT personnel to insure that all couplings meet the following requirements: couplings shall be evaluated according to reference radiographs in ASTM E505 by personnel qualified in accordance with the current edition of American Society for Nondestructive Testing Recommended Practice No. SNT-TCIA, to at least an NDT Level II. Couplings shall comply with the acceptance of level 3 or better for the Category A (porosity) discontinuity for a 5/8-inch casting thickness. For discontinuities in Categories B (Cold Fill, 1/8-inch casting thickness) and C (Shrinkage, 5/8-inch casting thickness) an acceptance criteria of Level I or better shall be required. No noticeable foreign material shall be permitted in the couplings.

In addition, all furnished couplings may be subject to further radiographic checks by the Engineer. At least 5 die cast couplings from each lot of 100 couplings or less may be selected at random and radiographed and evaluated. If two or more of the die cast couplings initially evaluated fails to pass the inspection, the entire lot will be rejected. If only one coupling fails to pass, at least 5 additional couplings may be selected at random, radiographed, and evaluated. All of the second batch of couplings shall pass or the entire lot will be rejected.

Components of the aluminum breakaway couplings shall comply with all other dimensions and specifications as outlined by the manufacturer and agreed upon by the Engineer.

The chemical composition of aluminum alloys used for manufacturing breakaway couplings shall meet appropriate specifications as follows:

- o Die cast aluminum breakaway couplings made from casting alloy #380 shall meet chemical requirements of the American Die Casting Institute as listed in their publication "Product Standards for Die Casting".

- o Extruded aluminum breakaway couplings made from specified alloys shall meet appropriate requirements as listed in ASTM Specification B221.

Assembled couplings with galvanized anchor bar studs installed shall withstand 1000 hours of Salt Spray (fog) testing according to ASTM Designation B117-85 without significant signs of corrosion.

Material certifications by the manufacturer along with test reports consisting of physical and chemical properties, results of restrained shear tests , axial tensile tests, cyclic tests, and salt spray (fog) tests, and a certified radiographic inspection report with film (die cast couplings only) shall be filed at the manufacturer's office for each manufactured lot of couplings. These certifications, test reports, and film shall be available for inspection by the Engineer upon request.