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E.F. Nordlin, R.F. Prodoehl, J.P. Dusel, and J.R. Stoker

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16. ABSTRACT

Results of a study to determine the effectiveness of the current breakaway slip base lighting standards with long mast arms when impacted by small cars are reported. Two full scale crash tests were conducted using a fully instrumented 1971 Ford Pinto, weighing 2265 lbs (10.1 kN); in both tests, the Pinto impacted a 35-ft (10.7-m) high, steel lighting standard (California Type 31) with a 30-ft (9.1-m) long mast arm having a total weight of 992 lbs (4.4 kN). The vehicle impact velocities, for the first and second test were 17.5 mph (28.2 km/hr) and 34.5 mph (55.5 km/hr) respectively. The slip base bolt tensions, torques, and resulting clamping forces were important parameters in the two crash tests. The tensions used in the slip base clamping bolts for this test series resulted in equivalent torques of almost twice those currently specified. The triangular slip base was oriented to provide the greatest base fracture energy and hence the most severe crash conditions for both tests.

It was concluded that the current Type 31 slip base used in California is an effective breakaway device when impacted by small cars, and relatively high slip base bolt torques do not seriously affect the slip characteristics of the base. The changes in vehicle momentums measured in both tests were below the desirable maximum of 750 lb-sec (3335 N. s) specified in NCHRP Report 153. The deceleration data and apparent injuries to the dummy also indicate a relatively mild crash for both tests.

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DIVISION OF CONSTRUCTION AND RESEARCH
TRANSPORTATION LABORATORY
RESEARCH REPORT

Dynamic Tests Of Breakaway Lighting Standards Using Small Automobiles

FINAL REPORT
CA-DOT-TL-6490-1-75-47
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75-47

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

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CALIFORNIA DEPARTMENT OF TRANSPORTATION

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STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF STRUCTURES & ENGINEERING SERVICES
OFFICE OF TRANSPORTATION LABORATORY

December 1975

TL No. 636490
Item D-4-85

Mr. C. E. Forbes
Chief Engineer

Dear Sir:

I have approved and now submit for your information this final research project report titled:

DYNAMIC TESTS OF BREAKAWAY
LIGHTING STANDARDS
USING SMALL AUTOMOBILES

Study made by . . . . Structural Materials Branch

Under the Supervision of . . . . E. F. Nordlin, P. E.

Principal Investigator . . . . J. R. Stoker, P. E.

Co-Principal Investigators . . . . J. P. Dusel, Jr., P. E.
and
R. F. Prodoehl, P. E.

Report Prepared by . . . . R. F. Prodoehl, P. E.

Very truly yours,

George A. Hill

GEORGE A. HILL
Chief, Office of Transportation Laboratory

Attachment
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ACKNOWLEDGEMENTS

This work was accomplished in cooperation with the United States Department of Transportation, Federal Highway Administration, as Item D-4-85 of work program HPR-PR-1(11), Research, and was titled, "Dynamic Tests of Breakaway Lighting Standards Using Small Automobiles". The contents of this report reflect the views of the Transportation Laboratory which is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation. It should also be recognized that the opinions, findings, and conclusions expressed in this publication are not necessarily those of the Federal Highway Administration.

The investigators appreciate the fine efforts of Transportation Laboratory employees who assisted with the research: L. Staus, L. Wilson, R. Pelkey, J. Keesling, D. Parks - testing and data reduction; R. Mortensen, K. Wilson - photography; and R. Johnson, S. Law, D. Gans - instrumentation.

Special appreciation is also due J. A. Creed and L. R. Johnson of the Caltrans Office of Structures and R. L. Stoughton of the Transportation Laboratory who served as consultants on this project.

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I. INTRODUCTION

The triangular steel lighting standard slip base was first developed and tested in 1967 by the Texas Transportation Institute(1). Their research objectives were met; they developed a slip base that was feasible, multi-directional, and was adaptable to existing luminaire supports. In 1968 the California Department of Transportation (Caltrans) performed a series of full scale dynamic impact tests on lighting standards with various types of breakaway devices, and in two of the tests the multi-directional slip base was used. Under the conditions of the 1968 California tests, the multi-directional slip base was an extremely effective breakaway device when impacted at both high and low speeds by a large automobile, and was considered superior to the other designs tested in that series(2).

The breakaway characteristics of the triangular slip base are dependent on the coefficient of friction and the clamping force on the slip planes. The clamping force must be large enough to prevent slip base separation when a lighting standard is subjected to dead load and wind load, yet small enough to insure low energy slippage when the standard is impacted. Tensions in the three slip base bolts which are easily varied but not so easily measured, control the total clamping force. The ideal slip base bolt tension which results in favorable breakaway characteristics and yet provides adequate clamping under severe wind loading is difficult to calculate and obtain due to two major factors. First, theoretical friction force calculations have not been adequately verified. Secondly, bolt torque, especially considering the use of hot-dipped galvanized bolts and nuts, is an inaccurate means of obtaining a specified bolt tension, as indicated in the torque-tension study conducted on 7/8-in. (22.2-mm) galvanized A325 slip base bolts prior to impact testing.

Since the performance of the 1968 crash tests, the designs of lighting standards and slip bases used in California have been changed. Larger lighting standards with longer mast arms (up to

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30 ft or 9.1 m) are now used on many freeways, as designers are providing more clear space between the edge of the roadway and fixed objects. The current slip base design used in installations where the California Type 30 and 31 steel lighting standards are specified (see Figures 1 and 2) is patterned after that developed by the Texas Transportation Institute, but it has been modified to fit the larger diameter, thicker walled poles with longer mast

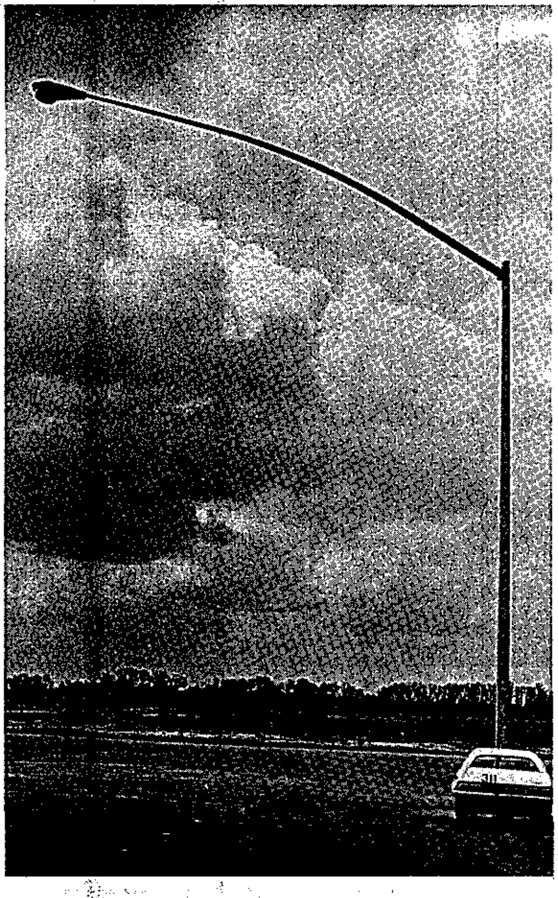

Figure 1. OVERALL VIEW OF FORD PINTO AND CALIFORNIA TYPE 31 LIGHT STANDARD.

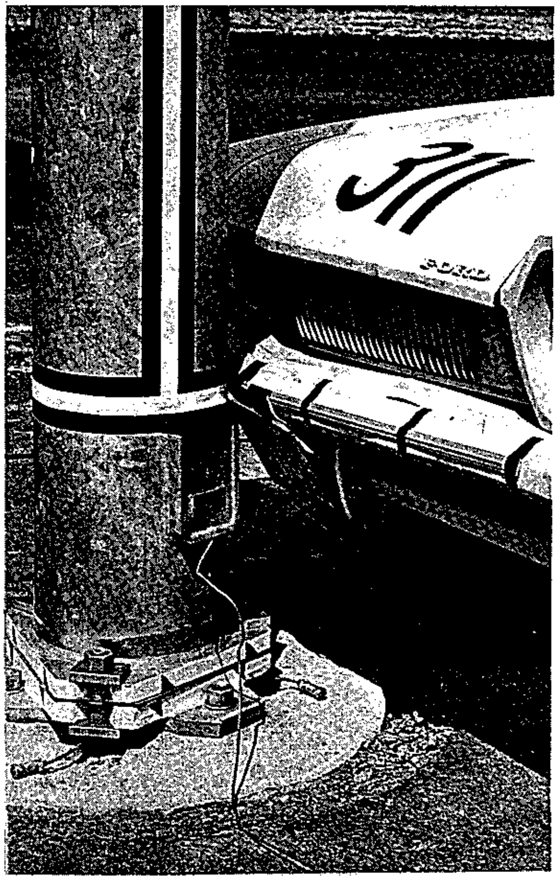

Figure 2. CLOSE-UP VIEW OF TYPE 31 POLE AND SLIP BASE AND FRONT OF PINTO.

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arms (3,4). In contrast to the previous developmental tests performed by Texas Transportation Institute and California Division of Highways, the currently used slip base is hot-dip galvanized, a keeper plate has replaced shear pins to prevent the clamping bolts from "walking" out of the slots due to wind vibration, and the diamter of the slip base clamping bolts has been reduced from 1 1/8 in. (28.6 mm) to 7/8 in. (22.2 mm). These modifications, though relatively minor, influence the slip characteristics of the base. Also due to the significant increase in wind induced loads possible with the 30-ft (9.1-m) long mast arm available for use on the Type 31 lighting standard, it was deemed necessary to increase the tension in each of the three slip base bolts; this resulted in a total clamping force considerably above that used in previous tests. The effect of these modifications on the effectiveness of the slip base was unknown.

The recent interest in reducing harmful automobile exhaust by-products and increasing vehicle fuel economy has greatly increased the number of small compact vehicles on the highway. With the increase in the size of the lighting standards and mast arms and the decrease in the size of automobiles, questions have arisen as to the breakaway effectiveness of the slip base when impacted by small as well as large vehicles. Until the completion of this research project these questions were unanswered, as no slip base lighting standard crash tests had been performed using small vehicles, nor had any crash tests been conducted using lighting standards with 30 ft (9.1 m) mast arms.

The objective of this project was to evaluate the effectiveness of the slip base currently used on California Type 31 lighting standards when subjected to full scale vehicle impact tests by small automobiles. The tension in each slip base bolt was accurately measured prior to both tests and was an important parameter in the evaluation. Suggested crash test procedures as specified in the

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NCHRP Report 153, "Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances"(5), were followed throughout this project. A color movie including before and after documentary coverage of the vehicle and lighting standard, and high-speed data reviews of the crash tests has been prepared as a part of this report.

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II. CONCLUSIONS

The following conclusions are based on results from full scale Crash Tests 311 and 312 of a Ford Pinto automobile impacting a California Type 31 lighting standard. It was found that:

1. The triangular steel slip base currently used on California Types 30 and 31 lighting standards is an effective breakaway device when impacted by small automobiles. The base slips with a relatively low loss in vehicle momentum at both low and moderate vehicle impact velocities, thus offering minimal breakaway resistance at impact.

2. A relatively high average slip base bolt tension in each clamping bolt of almost twice the tension currently used in slip base bolts for Type 30 and 31 standards (up to 19,800 lbs or 88.1 kN) did not adversely affect the slip characteristics of the base tested.

3. The trajectory and final position after impact of the 35-ft (10.7-m) high Type 31 steel pole with a 30-ft (9.1-m) long steel mast arm under the test conditions used did not create serious hazards or injuries to either occupants of the impacted vehicle or to passengers of vehicles in the adjacent traffic lanes.

4. Based on the results from both crash tests conducted, injuries to occupants of the impacting vehicle would be expected to be relatively minor provided that the impacting automobile has a roof.

5. Damages to the vehicle in both crash tests were repairable. Total costs of completely repairing the Pinto following Crash Test 311 were approximately $730.

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III. RECOMMENDATIONS

The use of the current Caltrans slip base design for Type 30 and 31 lighting standards as shown on drawings ES-30A and ES-30B of the Caltrans Standard Plans of January, 1975 should be continued with minor modifications as shown below:

1. Torques on each of the three slip base clamping bolts should be increased to 150 ft-lbs (203 N.m) to insure a long service life by reducing bolt fatigue.

2. The thickness of the rectangular plate washers used at the top and bottom of each slip base clamping bolt should be increased from 5/16 in. (7.9 mm) to 1/2 in. (12.7 mm) and minimum steel requirements should conform to the specifications of ASTM Designation: A108, grade 1018 cold drawn steel.

3. A maximum manufacturing tolerance of ±1/8 in. (±3.2 mm) should be specified on the 14-in. (356-mm) bolt circle diameter of both the upper and lower slip base plates to avoid adverse bending and yielding of plate washers.

These recommendations will be implemented through revised standard plans and specifications.

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IV. TECHNICAL DISCUSSION

A. Preliminary Research

Previous to vehicle impact testing, a study to determine the torque-tension relationship for 7/8-in. (22.2-mm) diameter galvanized A325 slip base clamping bolts was performed. The objective was to obtain a torque versus tension curve that could be used to establish average torque values for specified design bolt tensions.

Twelve 7/8-in. diameter (22.2-mm) by 4 1/2-in. (114-mm) A325 galvanized bolts were tested in a Bolt Load Meter, using a bolt grip length of 3 1/8 in. (79 mm). Galvanized 2 H nuts lubricated with a wax compound (Nox-Rust X185) were tightened against galvanized hardened flat washers. All nuts and six bolts were manufactured by the Bethlehem Steel Corporation and the other six bolts were manufactured by the National Bolt Company. The nuts were tightened in 20 ft-lb (27-N.m) increments and corresponding bolt tensions were recorded. The results are graphically represented in Figure 3. As shown, there is a large variation in bolt tensions at a given torque, and the spread in tensions increases as the torques increase. The only explanation for the consistently larger tension values obtained from the bolts supplied by the National Bolt Company is that the average pitch diameter was .006 in. (152 µm) larger than the average of those bolts supplied by the Bethlehem Steel Company, and as a result there was a tighter thread fit.

It was concluded from this preliminary study that the present system of applying torque to obtain a given bolt tension does not give repeatable results when using galvanized fasteners for

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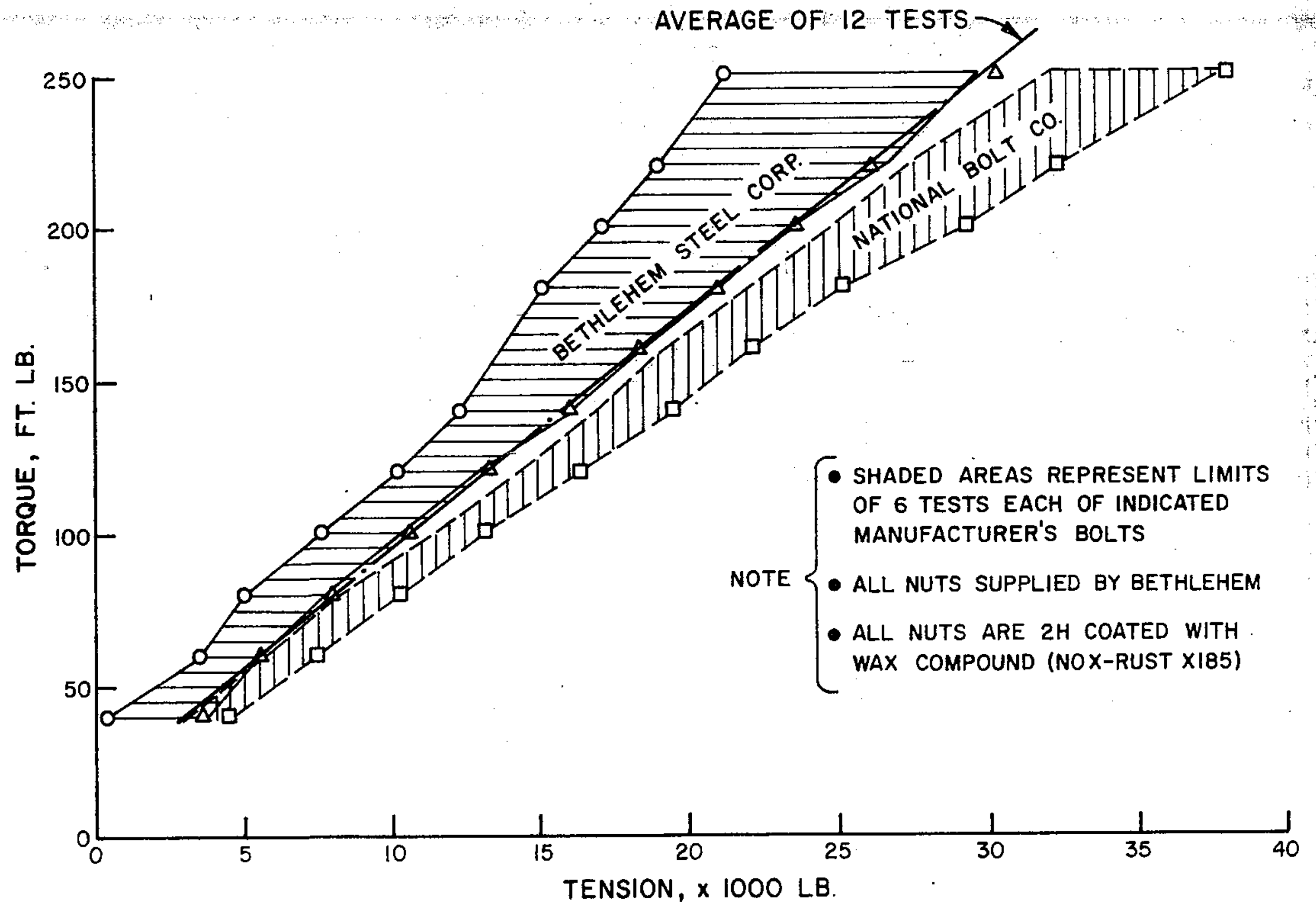

Figure 3. TORQUE-TENSION CURVE FOR A325 GALV. 7/8" Ø x 4 1/2" BOLTS.

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critical applications such as slip bases. Even though measured values of tension were widely scattered, an approximate maximum percent deviation from mean values was found to be ±25%, and the results of the crash tests prove the effectiveness of the slip base and show that it is not highly sensitive to wide variations in slip base clamping bolt tension. Therefore until a more accurate and economically feasible bolt tension measuring system is found, torque control of slip base bolts should suffice.

B. Test Conditions

1. Lighting Standard Details and Construction

The basic objective of these tests was to determine if the triangular breakaway slip base currently used on the California Type 30 and Type 31 lighting standards (4) is effective when impacted by a small automobile. The Type 31 lighting standard, which offers as an option the longest mast arm and heaviest pole of any breakaway lighting standard presently used on California highways, was used for the two crash tests. Both standards tested consisted of a steel pole 35 ft (10.7 m) high and a mast arm 30 ft (9.1 m) long, as detailed in the 1975 edition of the California Standard Plans shown in Figure 5. The pole weighs 650 lbs (2890 N) and the mast arm 280 lbs (1245 N). Attached to the end of the mast arm was a 700 watt luminaire weighing 62 lbs (275 N), bringing the total lighting standard weight to 992 lbs (4410 N) as shown in Figure 4.

The slip base used with the Type 31 lighting standard as detailed in the 1975 California Standard Plans, is shown in Figure 6. The top base plate consists of a triangular steel plate welded to the pole; the bottom base plate assembly consists of two quasi-triangular steel plates rotated 60° from each other and welded together or a similar shaped steel casting.

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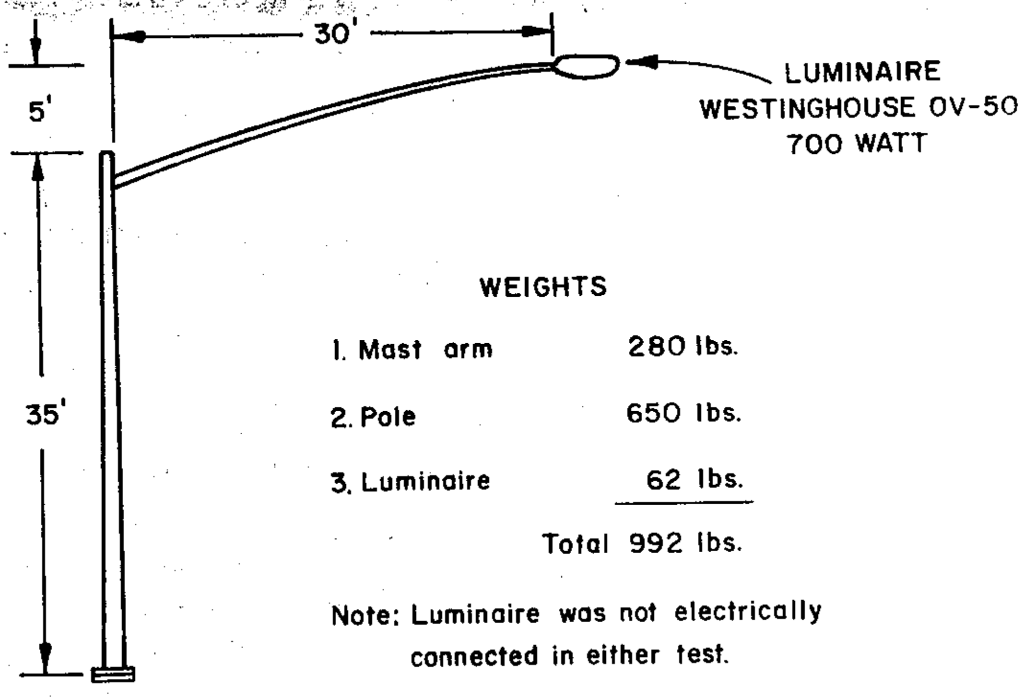

Figure 4. TYPE 31 LIGHTING STANDARD INFORMATION.

The top and bottom slip base plates are clamped together with three 7/8-in. (22.2-mm) diameter A325 galvanized bolts; the bottom base plate attaches to the footing with three 7/8-in. (22.2-mm) diameter high strength anchor bars cast into the concrete. The bolt circle diameter of both the slip base bolts and the anchor bars is 14 in. (356 mm). In these tests the slip base bolts were instrumented with strain gauges, which enabled the bolt tension to be accurately monitored previous to each test.

In both tests 2-in. x 2 3/4-in. x 1/2-in. (50.8-mm x 69.9-mm x 12.7-mm) galvanized A36 steel plate washers were used in place of

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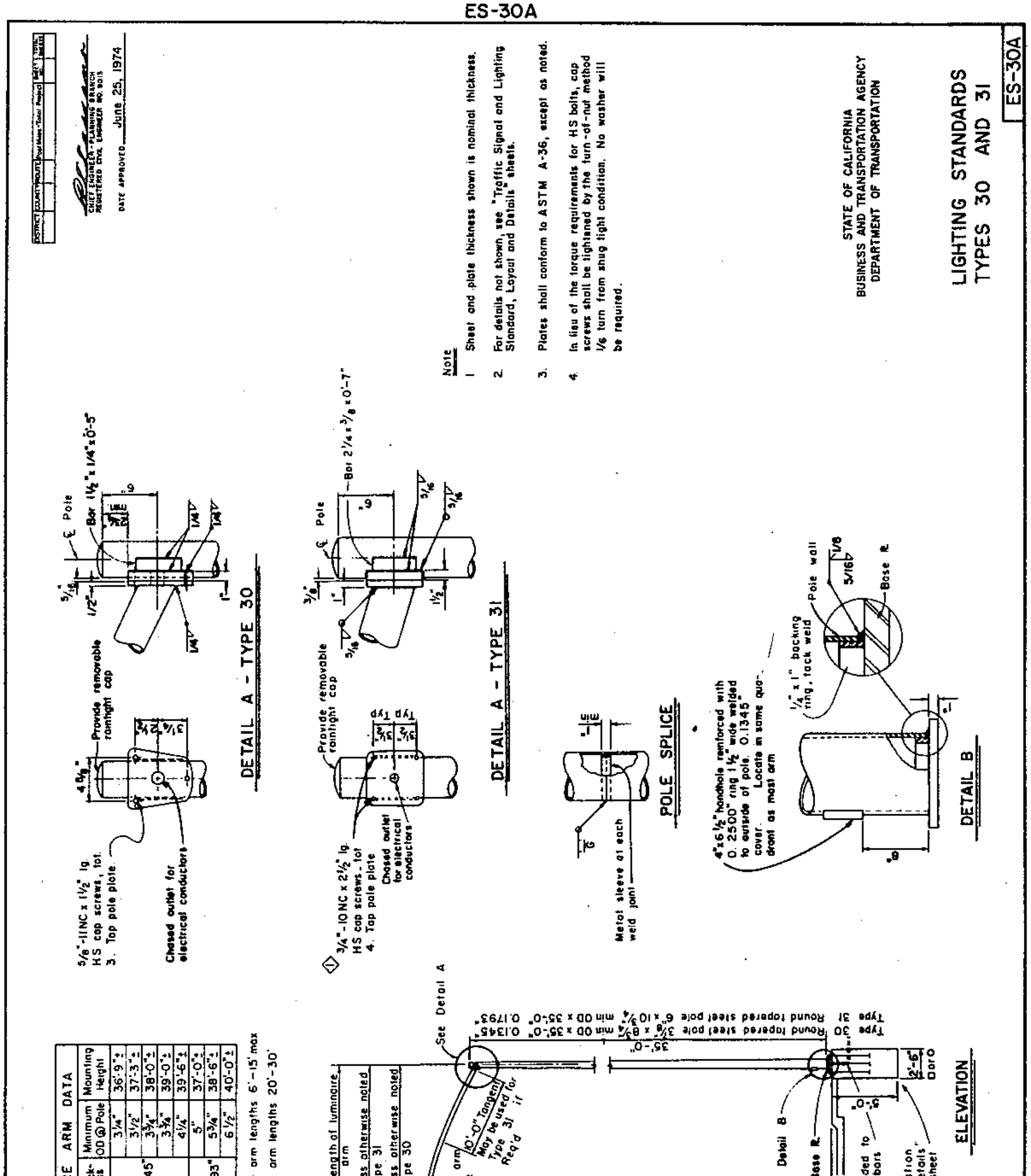

Figure 5. 1975 CALTRANS STANDARD PLAN ES-30-A, "LIGHTING STANDARDS TYPES 30 AND 31".

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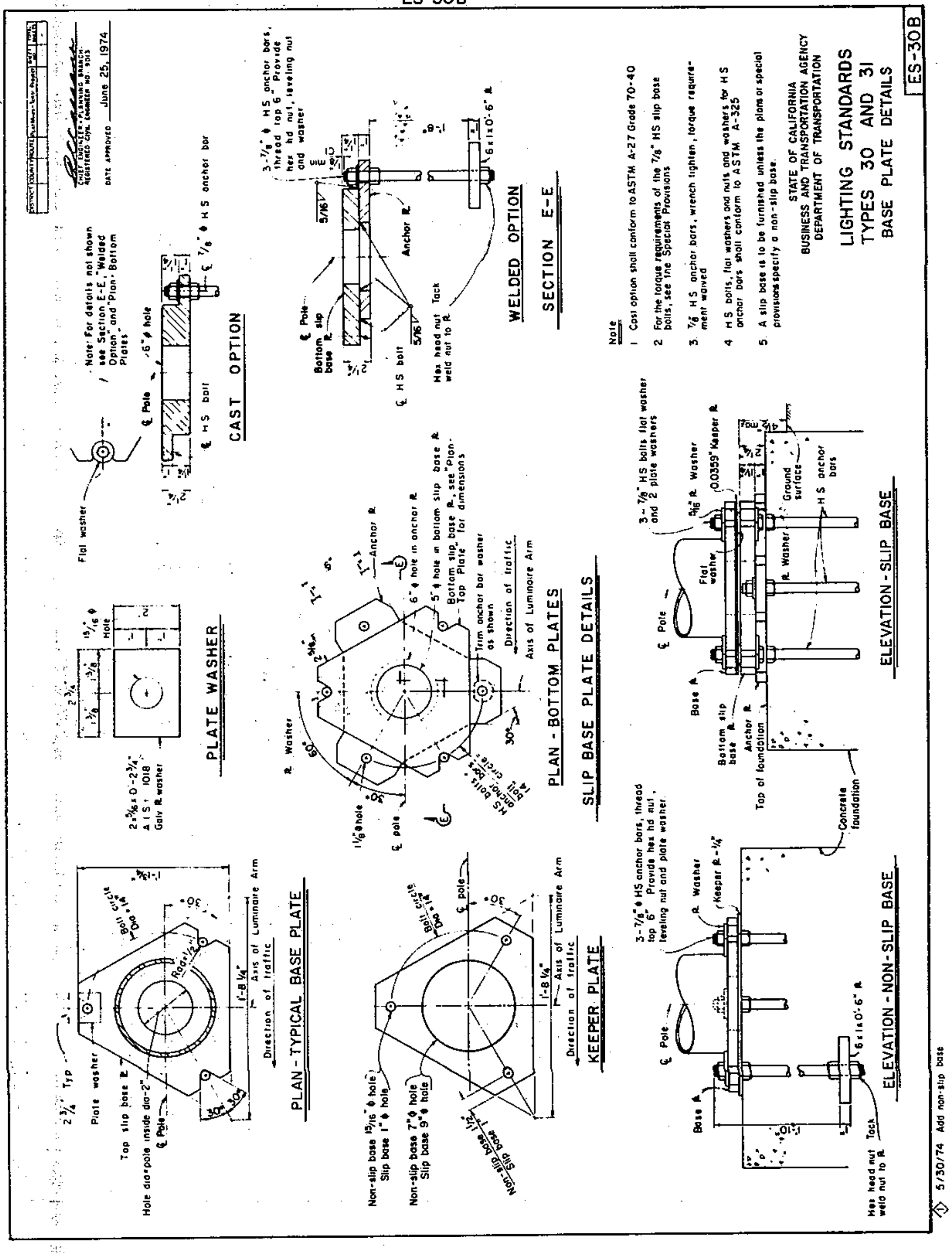

Figure 6. 1975 CALTRANS STANDARD PLAN ES-30-B, "LIGHTING STANDARDS TYPES 30 & 31 BASE PLATE DETAILS".

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the standard 2-in. x 2 3/4-in. x 5/16-in. (50.8-mm x 69.9-mm x 7.9-mm) galvanized plate washers made from AISI 1018 steel. A picture of the assembled slip base as used in the crash tests is shown in Figure 7. The 5/16-in. (7.9-mm) thick washers were replaced because during initial assembly of the slip base for Test 311 the standard bottom plate washers yielded severely in flexure due to relatively high slip base bolt torques which resulted in considerable loss of slip base bolt tension. Investigating the cause of why only the bottom plate washers bent, it was found that the bolt circle diameter of the bottom slip base plate (13 3/4 in. or 349.3 mm) was 3/8 in. (9.5 mm) smaller than that of the top plate (14 1/8 in. or 358 mm). The difference in bolt circle diameters prevented the slip base bolts from fitting snugly into the "V" notches on the bottom plate. This condition left very little of the bolt head bearing surface directly supported by the bottom plate through the bottom plate washer; the majority of the bolt tension was transferred to the bottom slip base plate via the plate washer in bending as this washer was spanning the bottom notch. Therefore the plate washers yielded due to a combination of high slip base bolt torques and the difference in the bolt circle diameters of the top and bottom slip base plates. After plate washer yield tests using 1/2-in. (12.7-mm) thick washers and slip base plates with varing clamping bolt circle diameters, it was concluded that by using 1/2-in. (12.7-mm) thick plate washers conforming to the ASTM Designation: A108, grade 1018 cold drawn steel, and specifying a maximum variation in slip base clamping bolt circle diameters of $\pm$ 1/8 in. ($\pm$ 3.2 mm), plate washer yielding at relatively high slip base bolt torques could be avoided.

The lighting standards were assembled and the footing constructed in accordance with the 1975 California Standard Plans and Standard Specifications(3) except for plate washers and bolt torques used on

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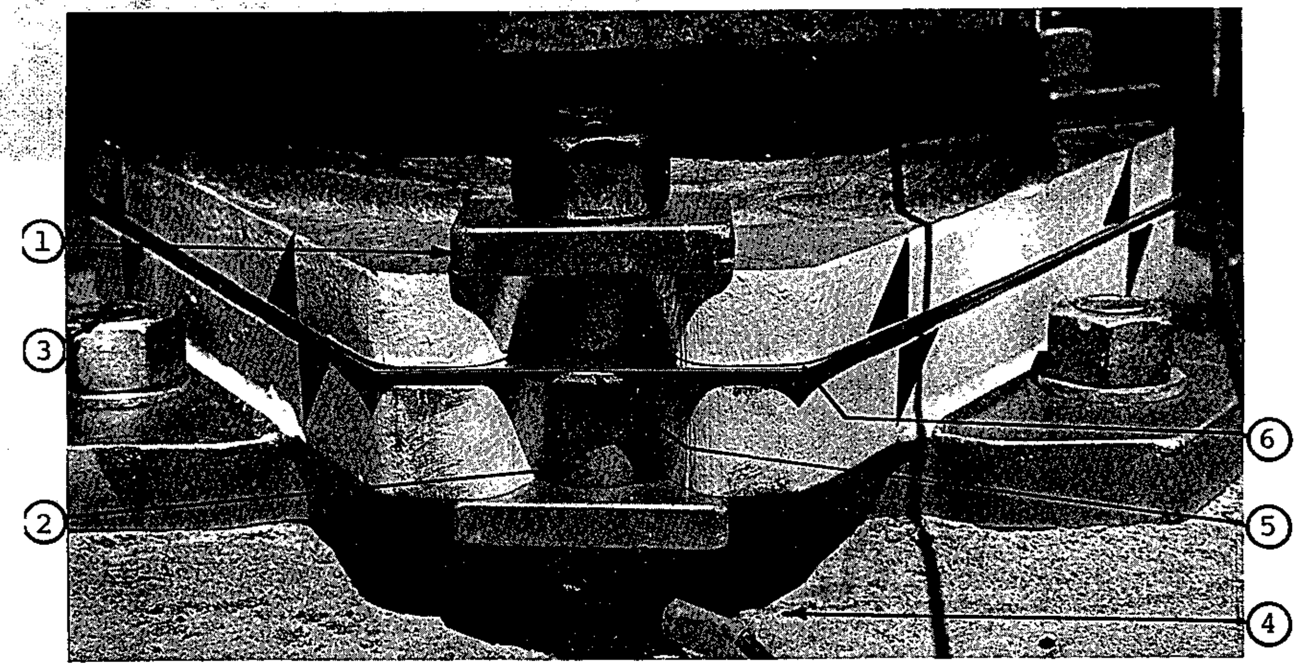

1. ASTM A36 steel plate washers modified from specifications shown in the 1975 Caltrans Standard Plans
2. 3- 7/8" A325 galvanized bolts instrumented with strain gages
3. 3- 7/8" HS anchor bolts cut flush with top of 2H galvanized nuts to allow top base plate to slip
4. Surface of foundation beneath slipbase bolt head relieved to provide minimum 1/8" clearance
5. hardened flat washer
6. 20 ga galvanized steel keeper plate

Figure 7. VIEW OF SLIP BASE USED WITH TYPE 31 LIGHTING STANDARDS IN CRASH TESTS 311 AND 312.

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the slip base bolts. The 2 1/2-ft (.76-m) diameter by 5-ft (1.52-m) deep unreinforced concrete footing was placed in a low cohesive, well graded, compacted soil, as specified in NCHRP Report 153. The original soil was excavated to a depth and surface radius of 6 ft (1.83 m) and replaced with the above specified soil. The concrete was poured into the 2 1/2-ft (.76-m) diameter augered footing hole embedding the lower portion of the anchor bars and leaving the top concrete surface 2 in. (50.8 mm) below final grade. The lighting standard and slip base were completely assembled on the ground. While the pole was still on the ground, the instrumented slip base bolts were tensioned to exclude the effects of any dead load on bolt tensions; the slip base bolts were not retightened after the pole was erected. The pole was lifted by a truck with a hydraulic hoist, placed on the footing and plumbed with the three leveling nuts. The footing was completed by grouting beneath the bottom base plate bringing xhe footing to final grade. For these tests the luminaire was not electrically wired. Both tests were conducted on a flat asphalt concrete surface at the Caltrans dynamic test facility within the California Highway Patrol Academy in Bryte, California.

2. Test Parameters

Since the objective of these tests was to evaluate the effectiveness of the breakaway slip base on a Type 31 lighting standard when impacted by a small automobile, the same type of car and lighting standard were used for both tests. The vehicle impact velocity and slip base bolt tension were different in both tests. The same 1971 Ford Pinto was used for both tests. All damaged parts (hood, radiator, bumper, etc.) resulting from the Test 311 crash were replaced with new parts before conducting Test 312. Although the NCHRP Report 153 does not recommend using the same vehicle for more than one crash test, it was felt that since there was no major structural damage to the car and all damaged parts were

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replaced with new ones the vehicle crush characteristics were not altered, and, thus substantial economic savings could be realized. A new pole, mast arm, luminaire, and slip base were used for each test. The bottom slip base plate assembly for Test 311 was the cast steel option and for Test 312 was the welded option (both shown in Figure 6). The slip base was oriented for both tests as shown in Figure 8. Results from research conducted by the Texas Transportation Institute(1) show that this base orientation produces the greatest resistance to slip.

The two items that were not kept constant were the vehicle impact velocity and the tension in the slip base bolts. Following recommendations in the NCHRP Report 153 for Test 1 of breakaway supports, the planned impact speed for Test 311 was 20 mph (32.2 km/hr). No suggestions are made in the NCHRP Report 153 to conduct a high speed test using small cars; however, it was felt that a 40 mph (64.4 km/hr) test was necessary, as results from two previous slip base crash tests conducted by Caltrans(2) using large cars show more extensive vehicle damage and larger decelerations at higher impact speeds.

An initial slip base bolt tension in each clamping bolt of 17,200 lbs (76.5 kN) was used in Test 312 because that is the calculated minimum value at which the slip base plates remain in contact during maximum design dead load and wind load. The prevention of separation of the upper and lower slip base plates is important from a fatigue standpoint as a large increase in an externally applied load only causes a small increase in clamping bolt tensions as long as plate separation does not occur(6). Once the slip base plates separate the tension in the clamping bolts increases in direct proportion with the external load. Thus by tensioning the slip base bolts enough to prevent plate separation even under maximum expected external loading, the cyclic stress range in each clamping bolt is reduced and hence the probability of bolt failure due to fatigue is decreased. A higher initial bolt tension of 23,600 lbs (105.0 kN) was used in Test 311 to not only insure complete plate contact but also provide for instances where excessive torque might be applied to slip base bolts.

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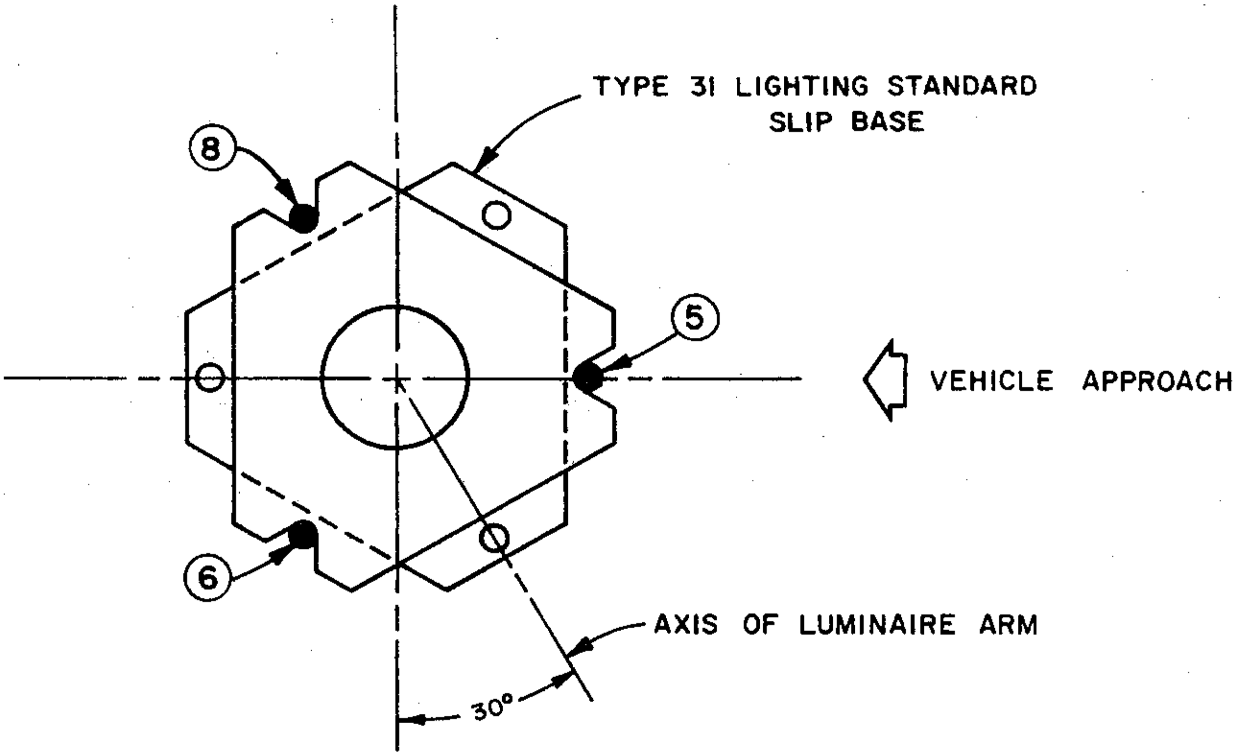

	BOLT TENSION (lb.)/APPROX. TORQUE (ft. lb.)		
	BOLT ⑤	BOLT ⑥	BOLT ⑧
CURRENT SPECIFICATION	8800/ 84	8800/ 84	12100/ 110
CRASH TEST NO.			
311 ⚠	18900/164	20100/173	20400/176
312 ⚠	15300/136	14600/130	15400/136

⚠ MEASURED 1-HOUR BEFORE TEST

Figure 8. SLIP BASE ORIENTATION AND INSTRUMENTED BOLT DATA.

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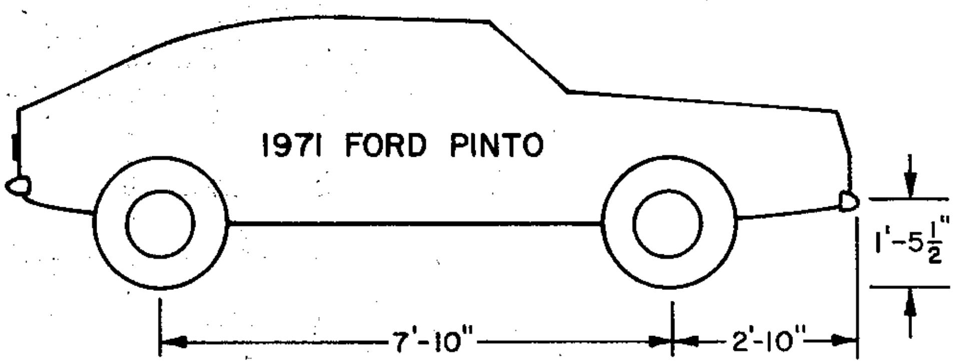
3. Test Equipment and Data Acquisition Systems

The test vehicle was a 1971 Ford Pinto weighing 2265 lbs (10.1 kN) including on-board instrumentation and a dummy. The gas tank, right front and rear seats, and spare tire were removed to obtain a desired weight of approximately 2250 lbs (10 kN). The dimensions of the vehicle are shown in Figure 9. The vehicle was controlled by a cable guidance system, consisting of a highly tensioned 3/8-in. (9.5-mm) wire rope and a guide plate. The guide plate, which was knocked off by a fixed steel post just prior to vehicle-lighting standard impact, was attached to the right front wheel spindle of the Pinto.



GROSS VEHICLE WEIGHT = 2265 lbs.
(includes weight of dummy (165 lbs.) and instrumentation)

Figure 9. TEST VEHICLE INFORMATION.

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High speed and normal speed movie cameras and still cameras were used to record the impact event and the condition of the vehicle and pole before and after impact. The high speed cameras were equipped with timing light generators which exposed reddish timing dots on the film at a rate of 1000 per second; thus a time base was established for each crash test. Targets attached to the side of the vehicle, the slip base, and ground locations within view of specific high speed cameras, provided a vehicle travel distance versus time relationship from the movies. A Vanguard Motion Analyzer was used for obtaining pertinent information from the high-speed film.

Tape switches were laid on the ground perpendicular to the vehicle path both upstream and downstream from the lighting standard. Five of the switches triggered flashbulbs in the field of view of the high speed cameras and five other switches produced sequential impulses which were recorded on a magnetic tape system, with an impressed timing cycle.

For recording the duration of pole and vehicle contact, an electrical circuit was connected so that the pole was grounded through the car while the two were in contact; when the pole separated from the car the circuit was opened.

To obtain data on the motions and deceleration forces a human would be subjected to during these impacts, an anthropometric dummy was placed in the driver's seat of the crash vehicle for both tests. The dummy, Sierra Stan (Model P/N 292-850), manufactured by Sierra Engineering Company, is a 50th percentile male weighing 165 lbs (734 N). Stan was restrained during Test 311 by both a lap belt and shoulder belt, but to determine more typical driver kinematics during the impact event, only a lap belt was used in Test 312.

Accelerometers were mounted at the center of gravity of the vehicle, and in the chest and head of the dummy to obtain deceleration data for use in judging the severity of injuries to the driver.

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C. Test Results

1. General Information

Figures 10 and 11 illustrate details of the two tests. The mast arm was at an angle of 60° to the vehicle approach line which results in the base being oriented in the direction that provides the greatest resistance to slip.

The velocities reported were calculated from information on the high speed film. The initial vehicle velocities are the average velocities over a 4-ft (1.2-m) interval just prior to impact, and the final velocities are the average values over a 2-ft (0.61-m) interval after impact.

The final velocity was taken at the point in time when a frictionless mass located on the front seat of the vehicle would have slid 2 ft (0.61 m) forward and hit the dash(5).

2. Test 311 Results

Test 311 was conducted to verify the effectiveness of the Type 31 lighting standard slip base under severe impact conditions, i.e., relatively high slip base bolt tension and slow vehicle impact velocity using a subcompact test vehicle. The intended speed of 20 mph (32.2 km/hr) was not reached due to a substandard performance of the automatic throttle control. The initial slip base bolt tension of 23,600 lbs (105.0 kN) per clamping bolt representing approximately 200 ft-lbs (271 N.m) of torque decreased with time, and just previous to the test was found to average 19,800 lbs (88.1 kN) representing approximately 170 ft-lbs (230 N.m) of torque. This is roughly twice the average tension resulting from the presently specified torques of 84 ft-lbs (114 N.m) and 110 ft-lbs (149 N.m) for the front bolts and rear bolt respectively, see Figure 8.

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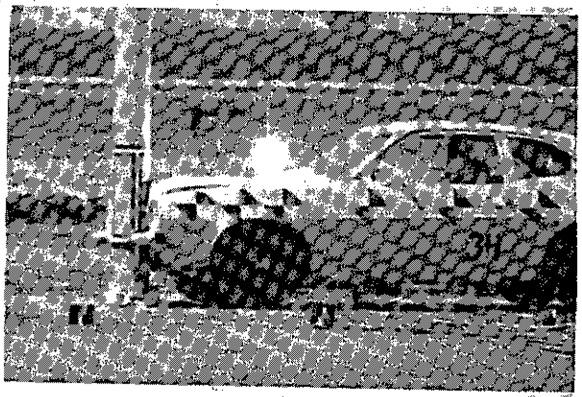

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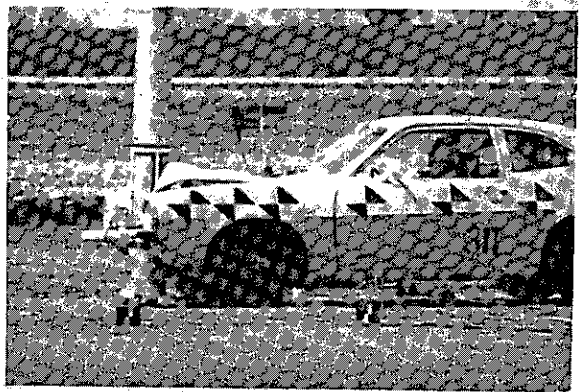

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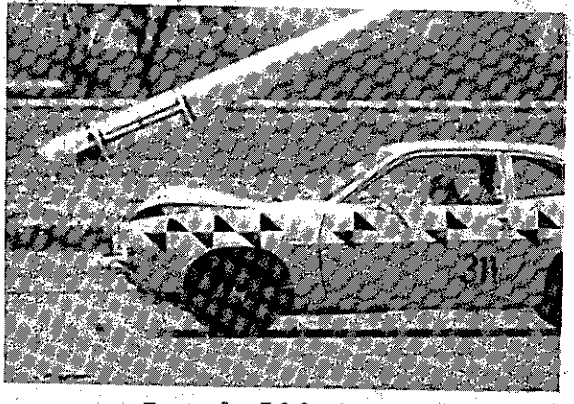

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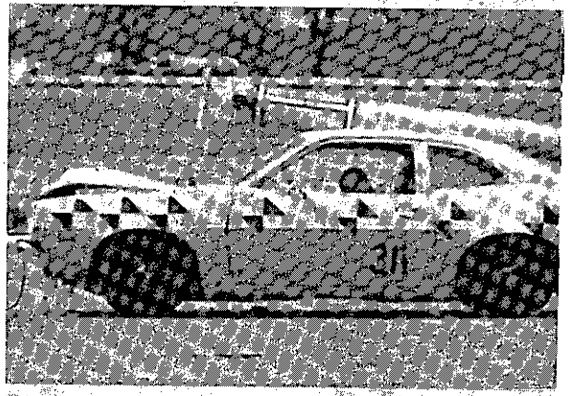

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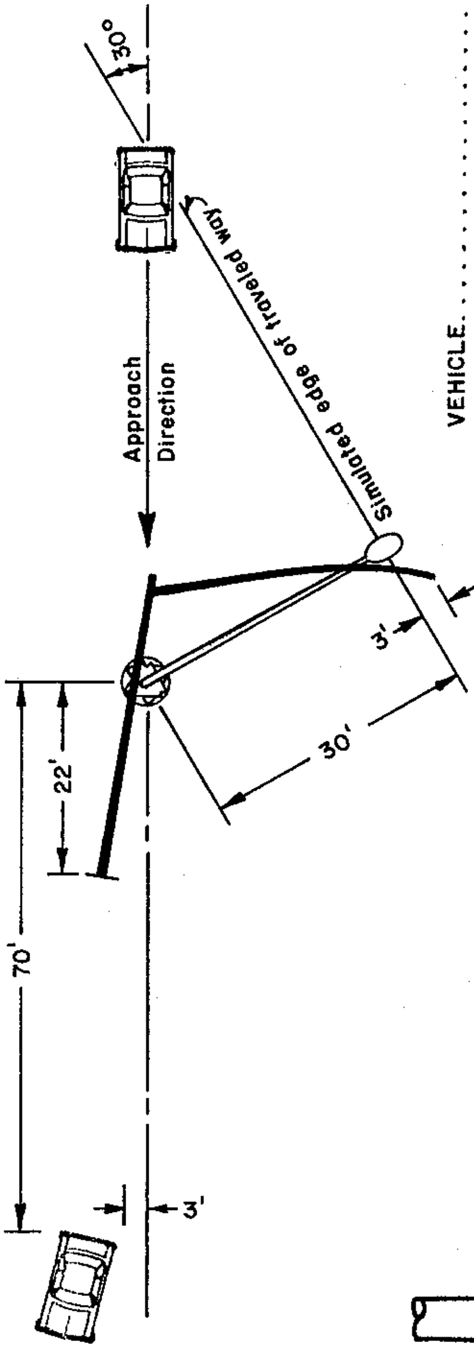

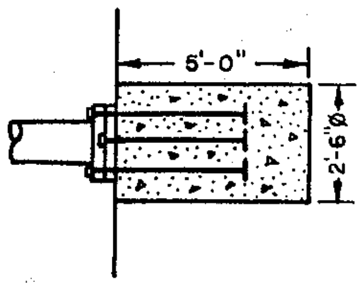

VEHICLE . . . . 1971 Pinto coupe
VEHICLE WEIGHT. . . . . 2265 lbs.
(including dummy and instrumentation)
DUMMY RESTRAINT. . . . . Lap and shoulder belts
IMPACT VELOCITY. . . . . 17.5 mph
IMPACT ANGLE. . . . . 30° from edge of pavement
MOMENTUM CHANGE. . . . . 689 lb. sec.
VEHICLE CRUSH (measured at bumper ht.). . . . . . . 17"
VEHICLE DECELERATION (max. 50 msec avg.)
LATERAL . . . . 1.30 G's
LONGITUDINAL . . . . 4.95 G's

TEST NO. 311
DATE. . . . . April 16, 1975
TYPE OF LIGHT STD. 31
POLE BASE OUTSIDE DIAM. . . . . 10 3/4"
MOUNTING HEIGHT. . . . . 40'-0"±
PROJECTED LENGTH OF MAST ARM. . . . . 30'-0"±
BREAKAWAY DEVICE. . . . . typical for Caltrans
Type 30 and 31 lighting standards

Figure 10. TEST 311 DATA SUMMARY SHEET

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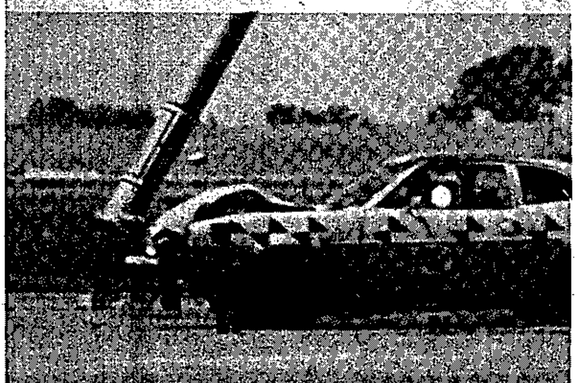
.025 SEC. BEFORE IMPACT

I + .100 SECS.



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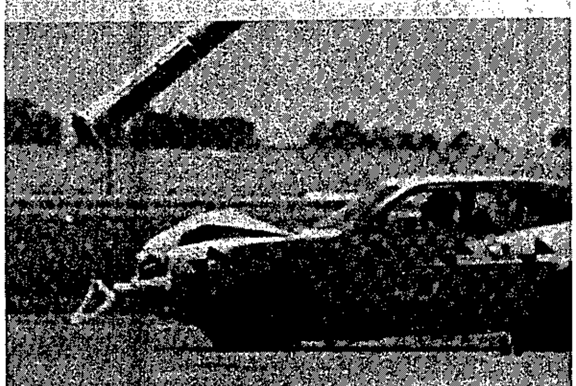

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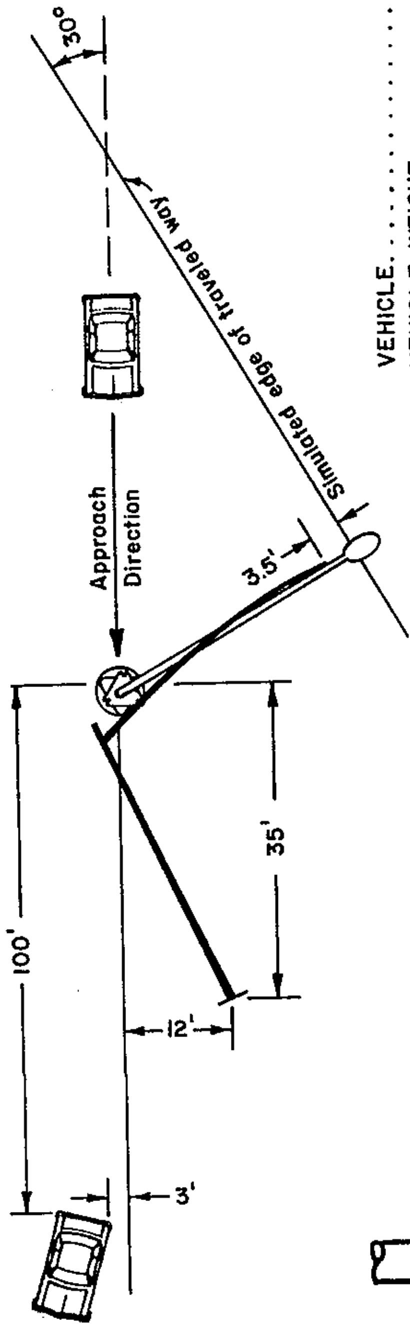

TEST NO. 312
DATE. May 30, 1975
TYPE OF LIGHT STD. 31
POLE BASE OUTSIDE DIAM. . . . . .10 3/4"
MOUNTING HEIGHT. . . . . .40'-0"±
PROJECTED LENGTH OF MAST ARM. . .30'-0"±
BREAKAWAY DEVICE. . . . . typical for Caltrans
Type 30 and 31 lighting standards

VEHICLE. . . . . .1971 Pinto coupe
VEHICLE WEIGHT. 2265 lbs.
(including dummy and instrumentation)
DUMMY RESTRAINT. . . . . .Lap belt only
IMPACT VELOCITY. .34.5 mph
IMPACT ANGLE. . . . . .30° from edge of pavement
MOMENTUM CHANGE. . . . . .746 lb. sec.
VEHICLE DAMAGE (measured at bumper ht.). . . . . . .18.5"
VEHICLE DECELERATION (max. 50 msec avg.)
LATERAL . . . . 1.00 G's
LONGITUDINAL. . . . . 4.85 G's
VERTICAL . . . . 3.55 G's

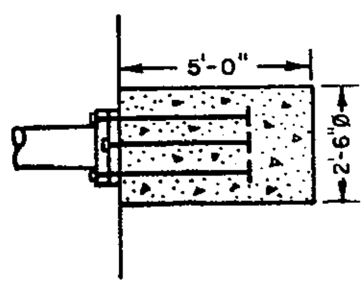

Figure 11. TEST 312 DATA SUMMARY SHEET.

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The test vehicle impacted the vertical pole 17 1/2 in. (445 mm) (bumper height) above the top of the footing, at a velocity of 17.5 mph (28.2 km/hr). The front end of the Pinto crushed considerably and the car was slowed to 10.8 mph (17.4 km/hr) which occurred .255 seconds and 4.5 ft (1.37 m) after impact. The pole base slipped after initial front end crush of the car, and was pushed along in front of the car for about 18 ft (5.5 m), as it was uplifted slightly above the top of the car. The pole hit the right edge of the car roof approximately the same time the luminaire arm hit the ground. The luminaire remained fastened to the luminaire arm until it contacted the asphalt concrete surface. The pole and luminaire arm remained intact, with the main pole coming to rest approximately parallel to the vehicle path, and the tip of the luminaire arm extending 3 ft (0.9 m) into the imaginary traffic lane. The car coasted to a stop 70 ft (21.3 m) past the initial car/pole impact point with the left rear wheel approximately 3 ft (0.9 m) to the right of the approach centerline.

Major vehicle damage was limited to the front end. The front bumper was pushed inward 17 in. (432 mm), the hood was buckled, and the radiator was pushed into the fan and the water pump as shown in Figures 12 and 13. There was no other engine damage. The roof received minor damage, a 1-in. (25-mm) deep dent, and no car windows were broken. The pole was not damaged at the vehicle impact point, but buckled at about the midpoint, as the top of the pole hit the ground the same time the bottom portion of the pole impacted the car roof. The luminaire arm bent in two places and both metallic and glass portions of the luminaire shattered upon hitting the asphalt concrete surface.

The dummy, restrained by both a lap belt and shoulder belt, pushed forward against the shoulder belt upon impact but was restrained from hitting any part of the interior of the car.

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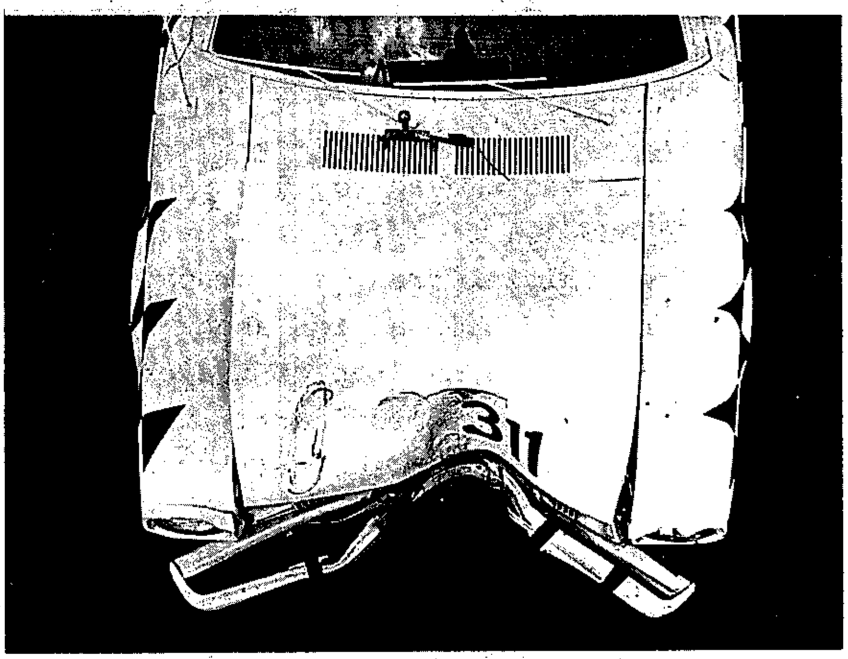
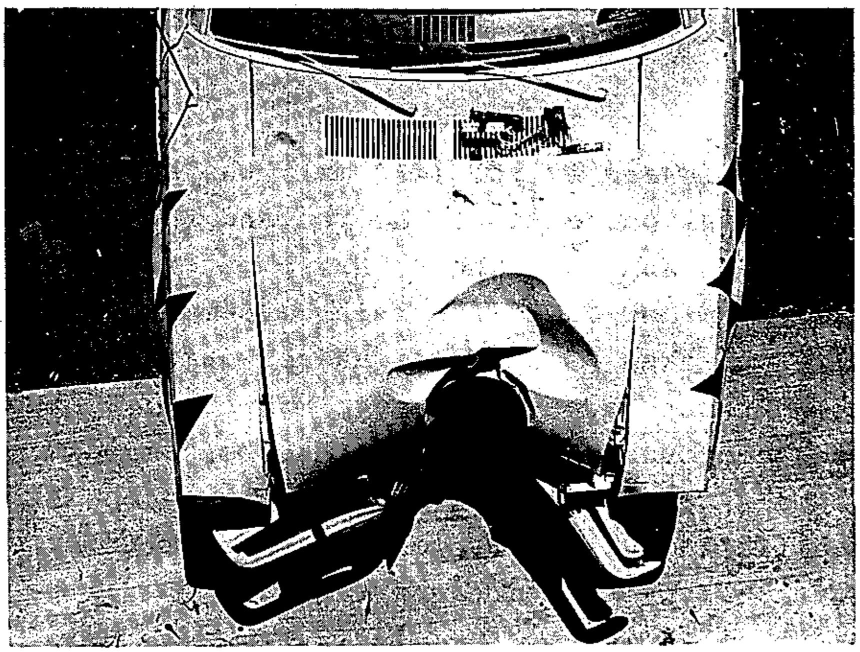


CRASH TEST 311



CRASH TEST 312

Figure 12. FRONT END DAMAGE TO FORD PINTO.

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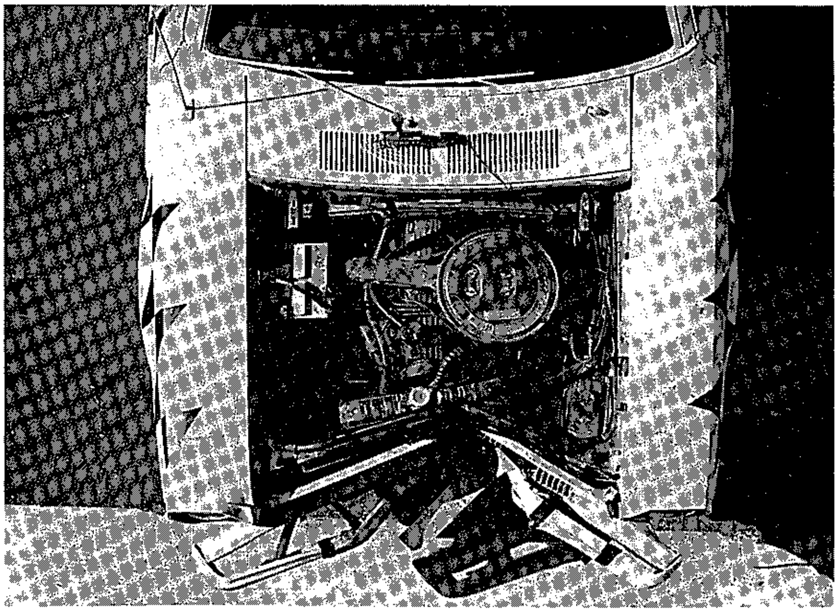
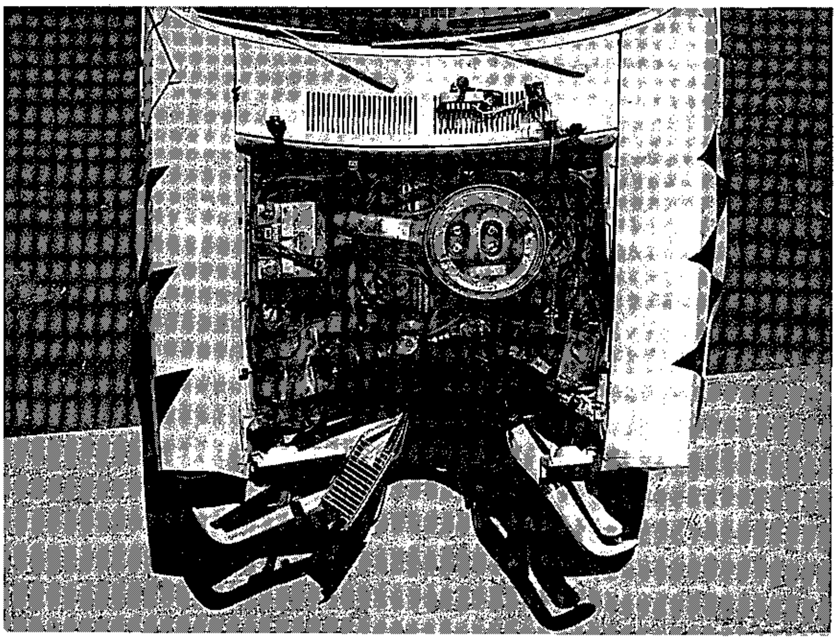


CRASH TEST 311



CRASH TEST 312

Figure 13. FRONT END DAMAGE TO FORD PINTO—HOOD REMOVED.

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3. Test 312 Results

Following the successful completion of Test 311, it was decided to run Test 312 at a higher speed to compare damage to the test vehicle and to observe the movement and final resting position of the Type 31 lighting standard. Each of the three slip base clamping bolts was initially tightened to 17,200 lbs (76.5 kN) representing approximately 150 ft-lbs (203 N.m) of torque, but as in Test 311 the bolt tension decreased with time and just previous to the test the average bolt tension was 15,100 lbs (67.2 kN) representing approximately 135 ft-lbs (183 N.m) of torque.

The proposed velocity of 40 mph (64.4 km/hr) was not attained due to missfiring of the engine of the vehicle. The vehicle impacted the pole at 34.5 mph (55.5 km/hr), similarly crushing the front of the car as in crash Test 311. The car slowed to 27.3 mph (43.9 km/hr), which occurred .218 seconds and 9.0 ft (2.74 m) after impact. The pole began to uplift about 7 ft (2.1 m) after impact and kicked up, clearing the roof by 6.5 ft (2.0 m). The top of the main pole hit the ground first, adjacent to the footing, and the pole came to rest at an angle of about 25° to the vehicle path. The luminaire arm and main pole remained intact with the tip of the luminaire arm located 3.5 ft (1.1 m) outside the imaginary traffic lane. The luminaire broke off of the luminaire arm immediately after car/pole impact and shattered upon hitting the asphalt concrete surface. Slip base bolt No. 5 (see figure 8) stayed with the bottom half of the slip base. The other two slip base bolts flew forward, one remaining with the keeper plate. The keeper plate and base plate after Test 312 (Test 311 similar) are shown in Figures 14 and 15. The emergency braking system in the car was finally applied to stop the vehicle 100 ft (30.5 m) past the impact point with the left rear wheel coming to rest about 3 ft (0.9 m) to the right of the approach line.

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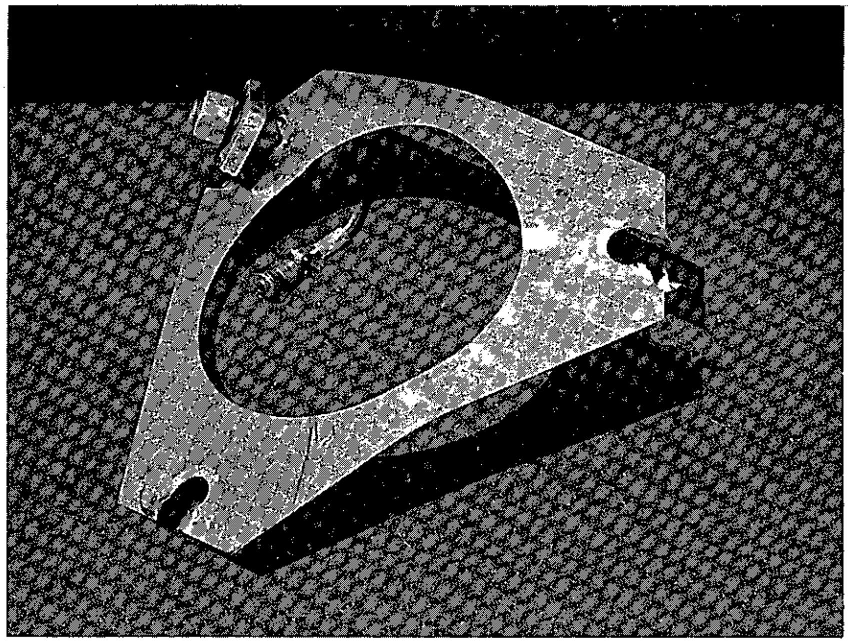

Figure 14. 20 GAGE KEEPER PLATE
AFTER TEST 312

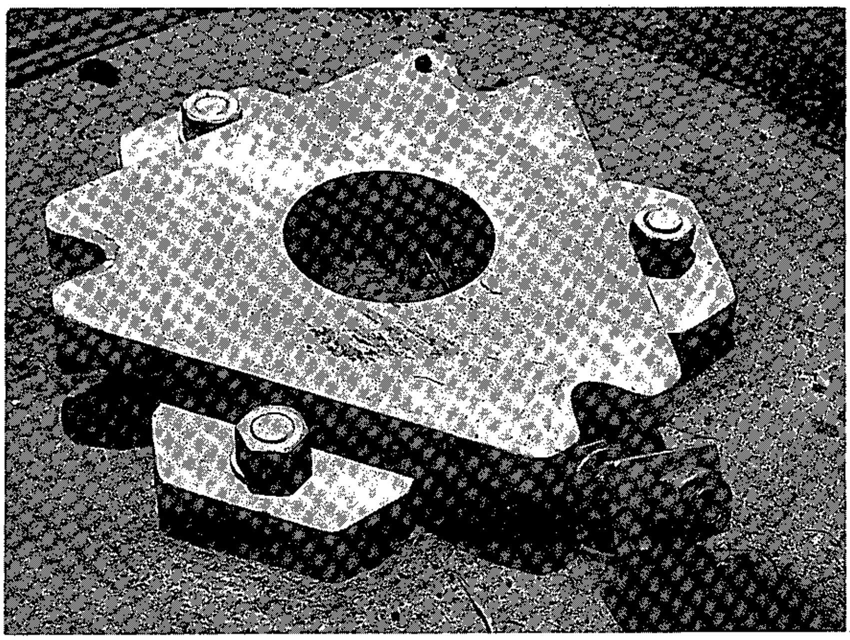

Figure 15. HOT-DIP GALVANIZED BOTTOM
SLIP BASE PLATE AFTER TEST 312

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The vehicle damage was limited to the front end of the car, and appeared to be more severe than the damage resulting from Test 311. The front bumper was pushed inward approximately 18.5 in. (470 mm) by the impact, buckling the hood and damaging the radiator similar to Test 311 as shown in Figures 12 and 13. The front fenders were visually sprung inwards, a condition that was not as noticeable after Test 311. The pole was undamaged at the impact point but buckled in two places as it hit the ground.

The dummy, restrained by a lap belt, leaned forward upon impact, hitting his chest and head on the steering wheel, then rebounded to an upright position. A live driver might have braced himself, preventing or reducing the steering wheel contact.

4. Discussion of Test Results

Figures 16 and 17 summarize the results of both tests. In Test 311 the intended speed of 20 mph (32.2 km/hr) was not reached, and the actual vehicle kinetic energy of 23,050 ft-lbs (31.3 kJ) is below the NCHRP Report 153 recommendation of 30,000 ± 4,000 ft-lbs (40 ± 5 kJ). A larger kinetic energy would have been desirable to conform to the uniform testing procedure recommended in NCHRP Report 153(5) however, the ability of the slip base to function properly is most severely tested when the vehicle impact kinetic energy is small. For Test 312 the impact kinetic energy was 90,050 ft-lbs (122.1 kJ), which was less than intended, but approximately four times higher than was achieved in Test 311.

In both tests the ability of the slip base to reduce the severity of a crash was demonstrated when after impact the pole base broke away as intended, and the vehicle slowed but continued on a straight

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ITEM	RESULTS	
	CRASH TEST 311	CRASH TEST 312
• Date of crash	April 16, 1975	May 30, 1975
• Planned velocity (mph)	20.0	40.0
• Initial velocity (mph) (average over a 4 ft interval prior to impact)	17.5	34.5
• Final velocity (mph) (average over a 2 ft interval after impact)	10.8	27.3
• Δ Velocity (mph)	6.7	7.2
• Δ Momentum (lb-sec)	689	746
• Time in pole contact (sec)	.181	.069
• Time to base separation (sec)	.055	.028
• Vehicle deformation (measured at bumpers height)	17 in.	18.5 in.
• Auto damage TAD / SAE	FC-4 / 12 FCEN2	FC-4 / 12 FCEN2
• Impact kinetic energy (ft-lb)	23,050	90,050

Figure 16. SUMMARY OF RESULTS FROM CRASH TESTS 311 AND 312.

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SEVERITY INDICATORS	RESULTS	
	CRASH TEST 311	CRASH TEST 312
1. Decelerations (50 msec average)		
a. C.G. of Vehicle		
Lateral	1.30 G's	1.0 G's
Longitudinal	4.95 G's	4.85 G's
Vertical	- - -	3.55 G's
b. Dummy		
Chest - Longitudinal	6.00 G's	4.3 G's
Head		
Longitudinal, Lateral, Vertical } resultant	6.32 G's	12.62 G's
2. Gadd severity index	5	34
3. Safety belt loads		
a. Shoulder	475 lbs.	- - -
b. Lap	95 lbs.	125 lbs.

Figure 17. INDICATORS OF CRASH SEVERITY FROM CRASH TESTS 311 AND 312.

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path without steering control (see Figures 18 and 19). The calculated momentum changes for Tests 311 and 312 are 689 lb-sec (3065 N.s) and 746 lb-sec (3318 N.s) respectively. These values are well below the maximum of 1100 lb-sec (4892 N.s) and close to the desirable maximum of 750 lb-sec (3335 N.s) specified in NCHRP Report 153 and AASHTO Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals (7). As was demonstrated in the previous Caltrans lighting standard crash tests using large automobiles (2), the higher impact velocity resulted in a somewhat larger momentum change. The vehicle front end crush reported was measured at bumper level and was the static condition after each test.

High speed film showed, as expected, that the base separated and the pole lost contact with the car faster in Test 312 than in Test 311. For Test 311 the pole first lost contact with the car .181 seconds after impact, but was again contacted as the car bumped the pole along for 18 ft (5.5 m). In Test 312 the pole remained in contact with the car for .069 seconds after impact, and once initially separated from the base, never contacted the car again. The final resting place of the pole was similar in both tests, and it can be assumed that as long as the main pole comes to rest approximately along the vehicle approach line that the mast arm will never encroach very far into the traffic lanes.

The deceleration data was collected to compare the relative severity of the tests and to estimate the extent of occupant injuries. Figure 17 lists the highest 50 msec average of vehicle and dummy decelerations, and seat belt loads. The only impact severity guidelines for the breakaway test listed in NCHRP Report 153 are that "dummy responses should be less than those specified by FMVSS 208, e.g., resultant chest acceleration of 60 g's, Head Injury Criterion of 1000, 1800 lb (8 kN) shoulder harness and 5000 lb (22.2 kN) total lap belt". The Gadd Severity Index, similar to the Head Injury Criterion, relates the lateral, vertical, and longitudinal head decelerations, and was computed to be 5 for Test 311 and 34 for Test 312. The extremely low value

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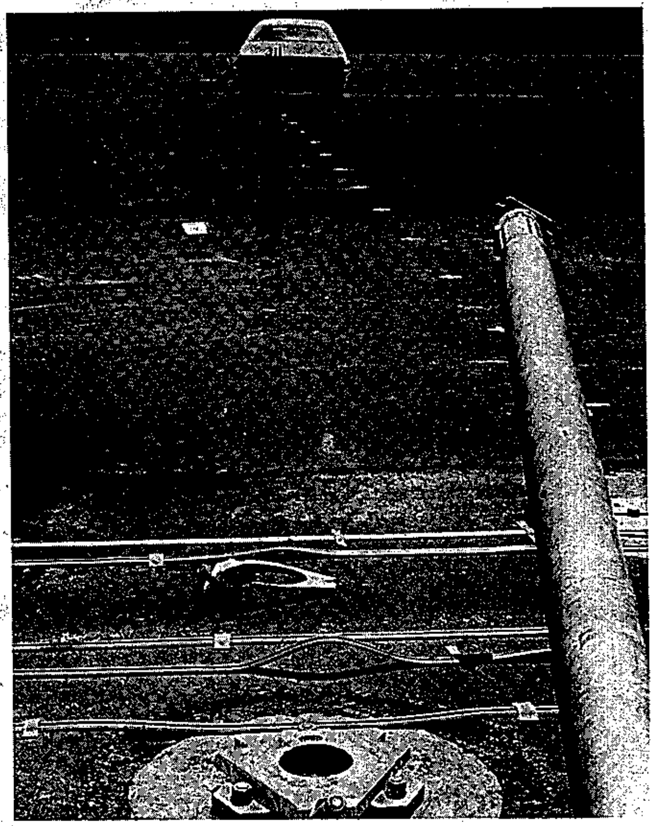

Figure 18. TEST 311 FINAL VEHICLE LOCATION

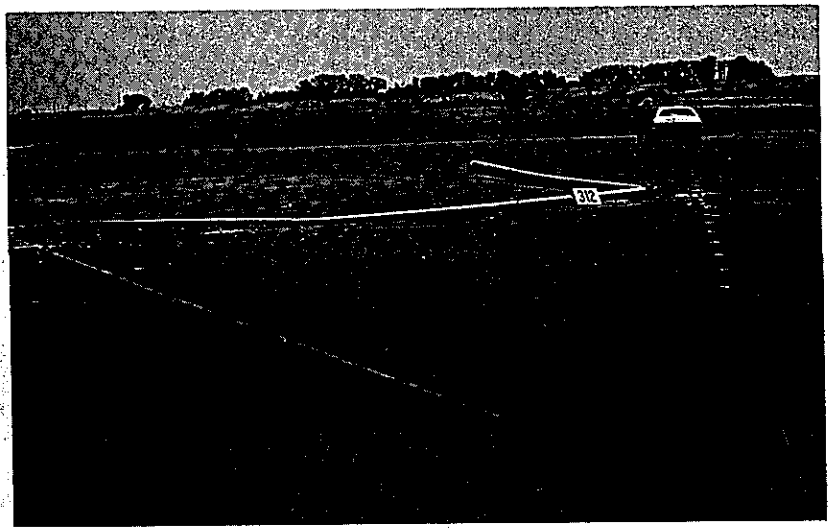

Figure 19. TEST 312 FINAL VEHICLE LOCATION

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(serious injury or death threshold is 1000) for Test 311 can be attributed to the shoulder belt preventing the dummy's head from striking the car's interior. The resultant head decelerations in Test 312 are higher than Test 311 because the dummy did strike the steering wheel. As seen in Figure 17 the chest decelerations of 6.0 g's and 4.3 g's, shoulder belt load of 475 lbs (2113 N), and lap belt loads of 95 lbs (423 N) and 125 lbs (556 N) for Tests 311 and 312 respectively, are all very small compared to the maximums specified above. These values as well as other deceleration data indicate both crash tests were relatively mild.

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V. REFERENCES

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2. Nordlin, E. F., Ames, W. H., and Fields, R. N., "Dynamic Tests of Five Breakaway Lighting Standard Base Designs", State of California, Transportation Agency, Department of Public Works, Division of Highways, Materials and Research Department, October 1968.

3. State of California, Department of Transportation, "Standard Specifications", Section 86, January 1975.

4. State of California, Department of Transportation, "Standard Plans", pp. 241, 242, January 1975.

5. Bronstad, M. E. and Michie, J. D., "Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances", NCHRP Report 153, Transportation Research Board, 1974.

6. Fisher, J. W., and Struik, J. H., "Guide to Design Criteria for Bolted and Riveted Joints", pp. 257-280, John Wiley and Sons, Inc., 1974.

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VI. APPENDIX

A. Crash Car Equipment

Following is a description of modifications made to the test vehicle prior to impact tests:

1. The test vehicle gas tank was removed, and a one gallon safety tank was installed in the trunk compartment and connected to the fuel supply line.

2. The right front seat was removed and three wet cell storage batteries (6, 8, and 12 volt) were mounted in its place. They supplied power for the on-board camera and instrumentation.

3. A solenoid-valve actuated CO_2 system was connected to the brake line for remote braking. With 700 psi in the accumulator tank, the brakes could be locked in less than 100 milliseconds after activation.

4. The ignition system was connected to the brake relay creating a failsafe interlock system. When the brake system was activated, the vehicle ignition was switched off.

5. The accelerator pedal was linked to a small electric motor which, when activated, opened the throttle. The motor was electrically activated using a manual toggle switch mounted on the top of the rear fender of the test vehicle.

6. A micro switch was mounted below the front bumper and was connected to the ignition system. A trip line installed 3 ft (.9 m) from the impact point triggered the switch, thus opening the ignition circuit and cutting the vehicle motor prior to impact.

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B. Photo-Instrumentation

Data film was obtained by high speed cinematography through the use of the six photosonic 16mm cameras (250-400 frames per second). These cameras were located on tripods to the rear and sides of the lighting standard as shown in Figure 1A and were electrically actuated from a central control console. A seventh Photosonic camera was located in the test vehicle to record motions of the anthropometric dummy, and in Test 312 an eighth Photosonic camera was mounted under the car to record slip base separation. The vehicle mounted cameras were triggered by a tether-line actuated switch mounted on the rear bumper.

Coverage of the impacts was also obtained by a 70mm Hulcher camera operating at a rate of 20 frames per second, and a 35mm sequence camera operating at 20 frames per second. Additional documentary coverage of the tests consisted of normal speed movies and still photographs taken before, during, and after each test.

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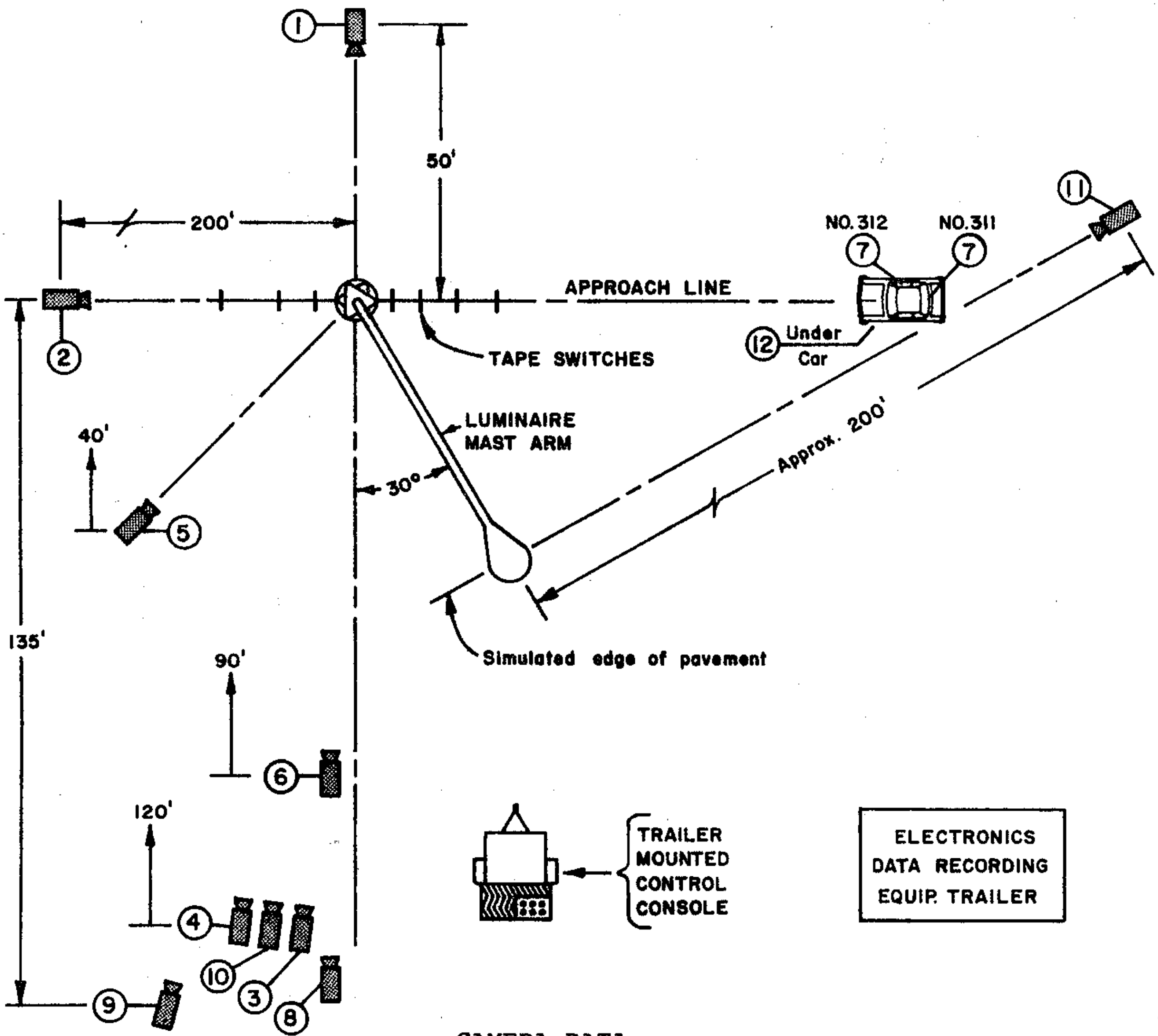

CAMERA DATA

(1) (2) (3)#	4 IN. LENS	PHOTO-SONICS AT 380 FPS+
(4)# (5)	2 IN. LENS	PHOTO-SONICS AT 380 FPS.
(6)	13 MM LENS	PHOTO-SONICS AT 380 FPS.
(7)	5.3 MM WA-LENS	PHOTO-SONICS IN TEST CAR
(8)	55 MM LENS	35 MM SEQUENCE CAMERA
(9)	150 MM LENS	70 MM SEQUENCE CAMERA
(10)# (11)*	25 MM LENS	BOLEX AT 24 FPS.
(12)*	13 MM LENS	PHOTO-SONICS AT 380 FPS.

*CAMERAS 11 AND 12 NOT USED FOR TEST NO. 311
#CAMERAS 3, 4, 10, PAN CAMERAS
+FRAMES PER SECOND

Figure 1A. CAMERA LAYOUT

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C. Electronic Instrumentation and Data

A total of eight Statham accelerometers, of the unbonded strain gage type, were used for deceleration measurement in Test 312. Of these, four were mounted, one in the chest and three in the head cavity, in the anthropometric dummy, and four were mounted on the floorboard of the test vehicle. In addition one Lebow seat belt transducer was installed on the dummy's lap belt.

Two Lebow seat belt transducers, one each on the lap and shoulder belt, and seven Statham accelerometers were used in Test 311. These instruments transmitted data through a 1000-ft (305-m) Belden #8776 umbilical cable that ran from a rear mounting bracket/receptacle on the test vehicle to a 14 channel Hewlet Packard 3924C magnetic tape recording system. This recording system was mounted in an instrumentation trailer located in the test control area. Figure 2A shows the location of the accelerometers and seat belt transducers in the test vehicle. Five pressure activated tape switches were placed on the pavement at fixed intervals in the vehicle approach path. When activated by the tires of the test vehicle, these switches produced sequential impulses which were recorded with the accelerometer and seat belt transducer signals on the tape recorder. Concurrently a 2 millisecond time cycle signal was impressed on the tape. All of the tape recorder data was subsequently played back through a Visicorder which produced oscillographic traces (line) on paper. Each paper record contained an analog curve of data from one of the nine instruments. Signals from the five tape records of accelerometer data had high frequency spikes which made analysis difficult, therefore, the original test data was filtered at 100 hertz with a Krohn-Hite filter. The smoother resultant curves gave a good representation of the overall dummy and vehicle deceleration without significantly altering the amplitude and time values of the deceleration pulse. Transducer and accelerometer records from both tests are presented in Figures 3A through 7A.

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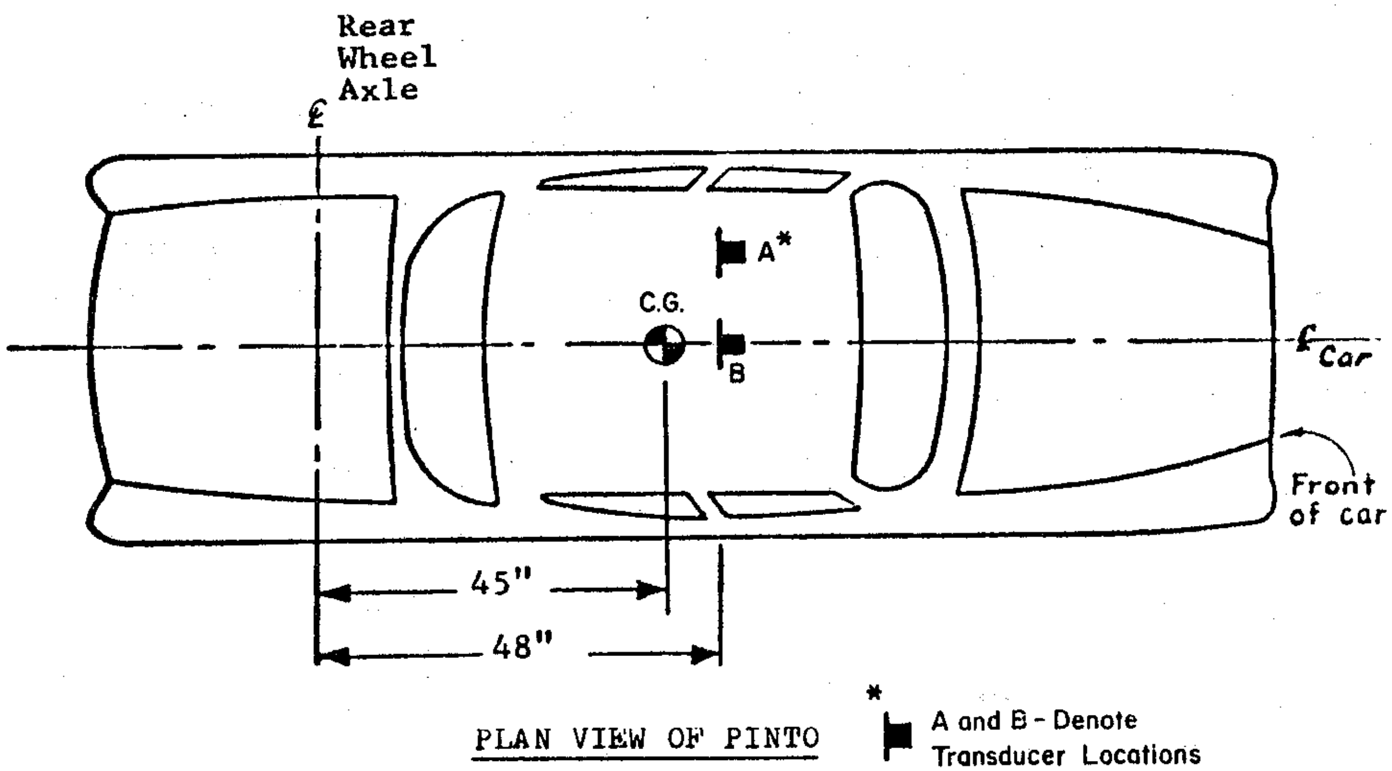

1. A Longitudinal------ Accelerometer in Dummy's Head
2. A Vertical---------- Accelerometer in Dummy's Head
3. A Lateral----------- Accelerometer in Dummy's Head
4. A Longitudinal------ Accelerometer in Dummy's Chest
5. B Laterial---------- Accelerometer at Vehicle's C.G.
6. B Longitudinal------ Accelerometer at Vehicle's C.G.
7. B Longitudinal------ Accelerometer at Vehicle's C.G.
8. B. Vertical--------- Accelerometer at Vehicle's C.G.(Test 312 only)
9. A Seat Belt Transducer Across Dummy's Lap
10. A Shoulder Belt Transducer Across Dummy's Body (Test 311 only)

Figure 2A. LOCATION OF ACCELEROMETERS AND TRANSDUCERS FOR CRASH TESTS 311 AND 312.

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The highest 50 msec average decelerations were calculated by a computer. The computer input consists of deceleration values, taken every 2.5 msec from the oscillographic trace, and the corresponding time after impact. The program averages the positive and negative values over the numerous 50 msec intervals. It then compares the absolute deceleration values of the intervals and reports the largest 50 msec average deceleration and the corresponding time interval after impact.

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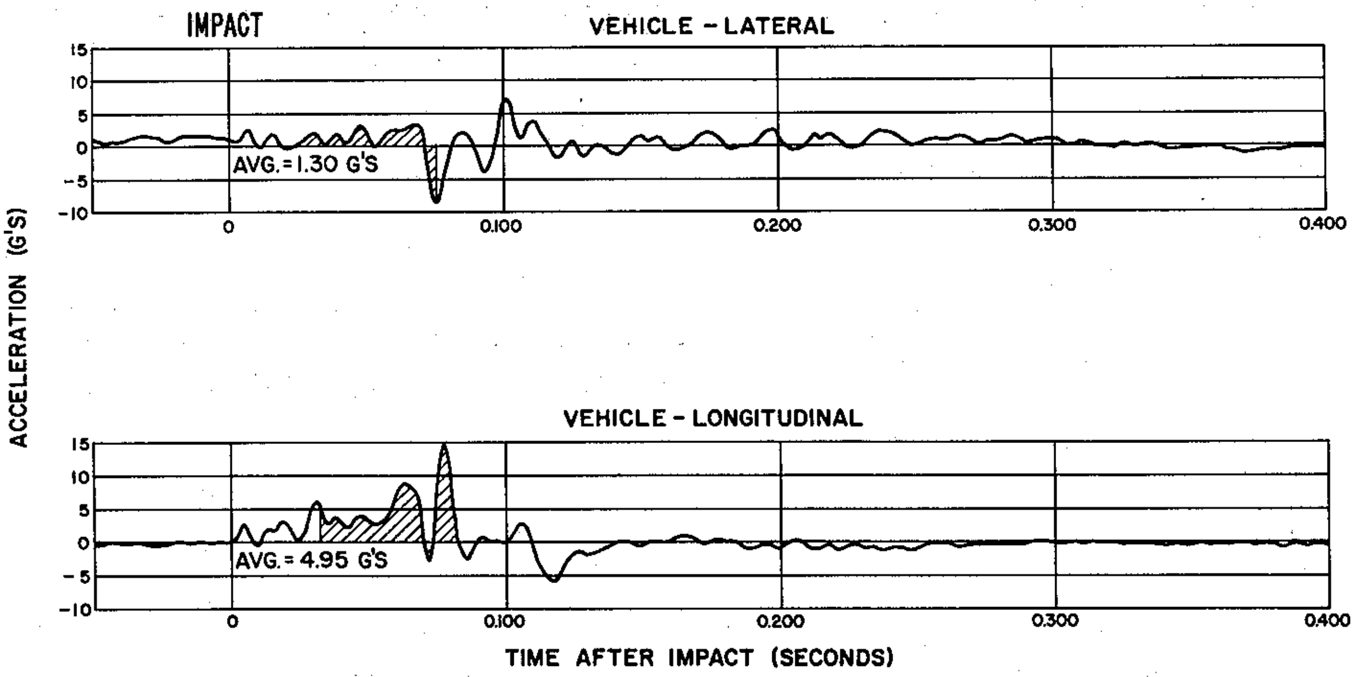
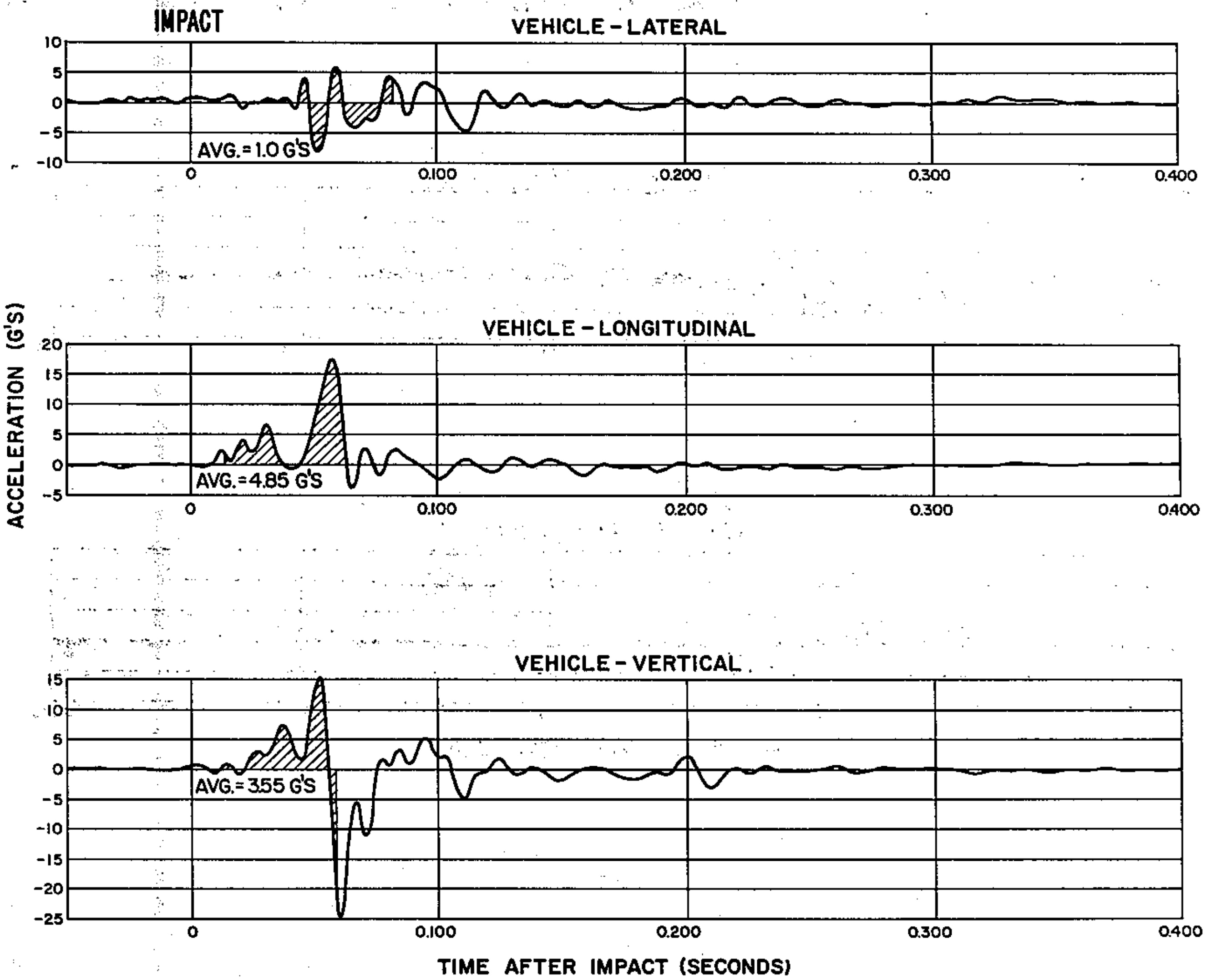


TEST 311, 17.5 MPH,

DATA FILTERED AT 100 HERTZ

Figure 3A. VEHICLE ACCELERATION VS TIME

ClibPDF - www.fastio.com

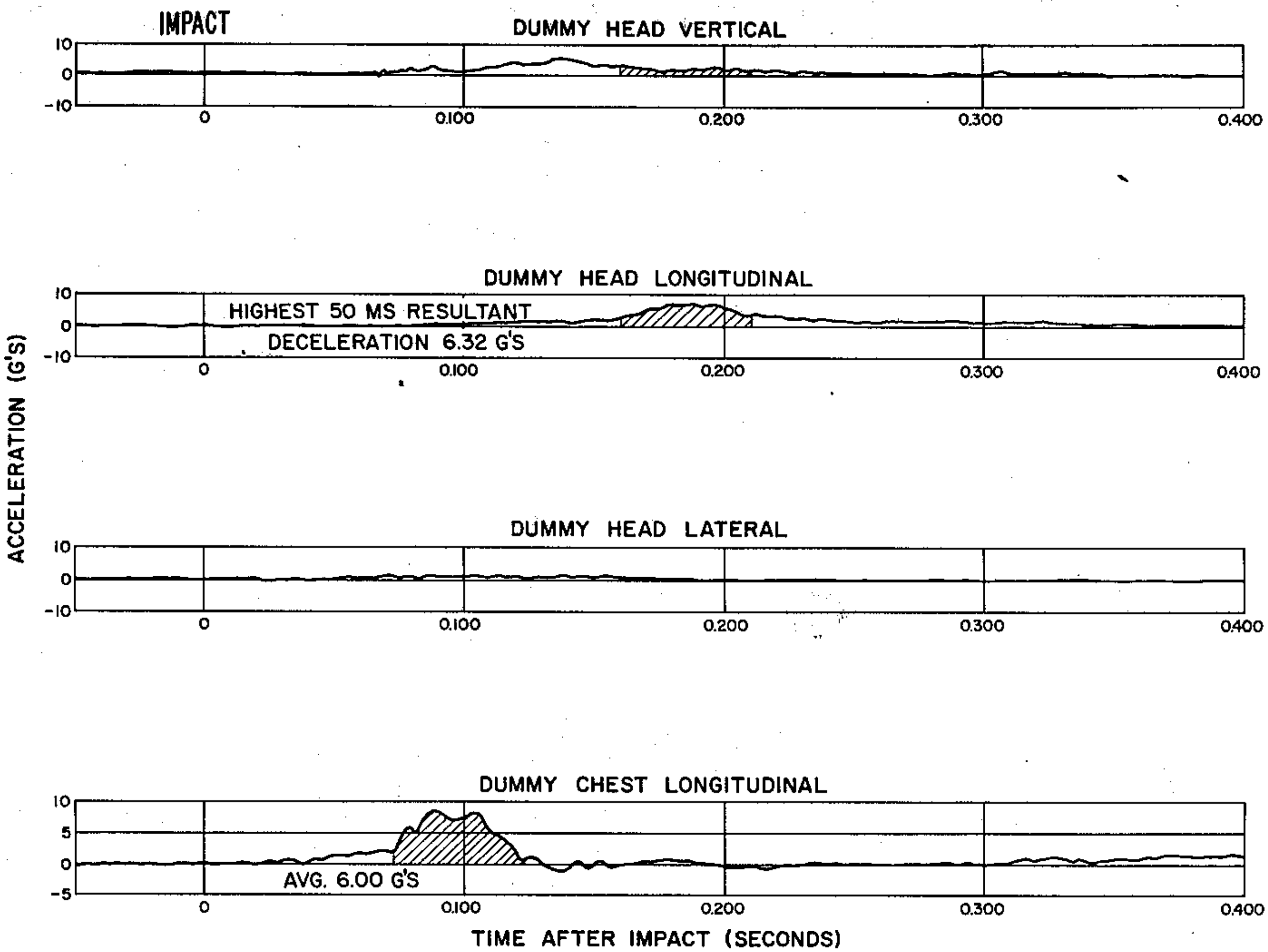


TEST 312, 34.5 MPH,

DATA FILTERED AT 100 HERTZ

Figure 4A. VEHICLE ACCELERATION VS TIME

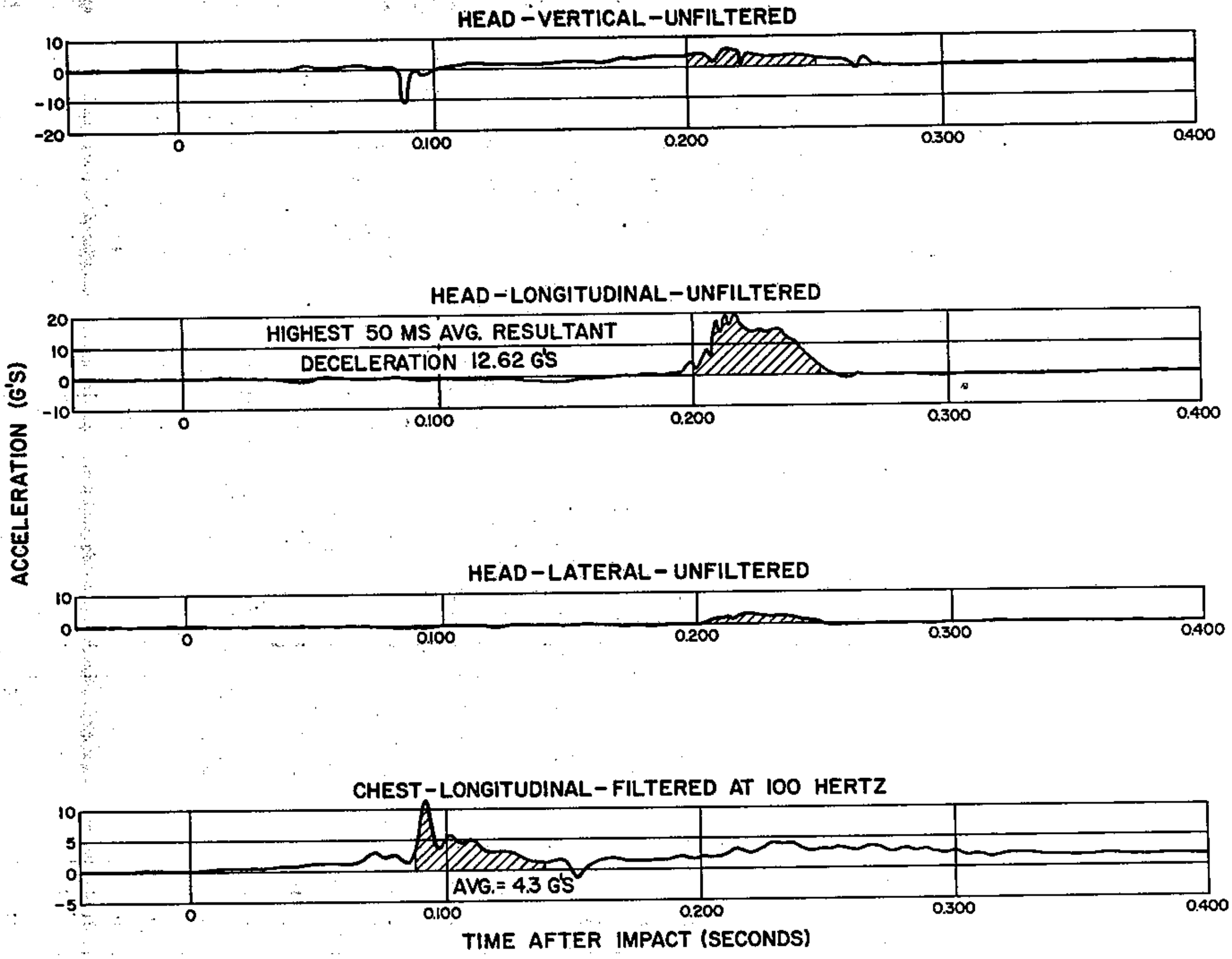
ClibPDF - www.fastio.com



TEST 311, 17.5 MPH, LAP AND SHOULDER BELT

Figure 5A. DUMMY ACCELERATION VS TIME

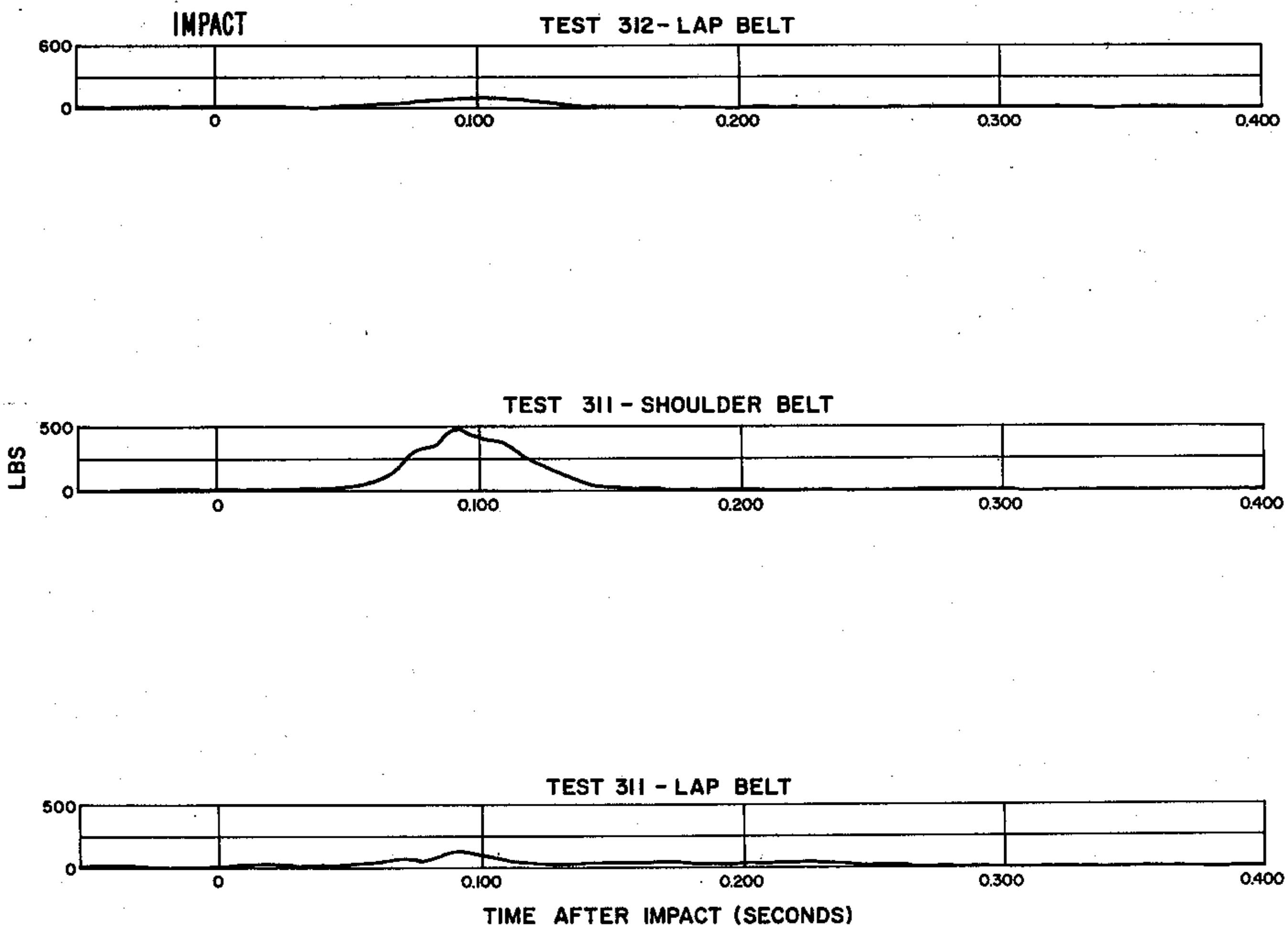
ClibPDF - www.fastio.com



TEST 312, 34.5 MPH, LAP BELT

Figure 6A. DUMMY ACCELERATION VS TIME

ClibPDF - www.fastio.com



DATA UNFILTERED

Figure 7A. SEAT BELT LOAD VS TIME

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