MULTI-DIRECTIONAL SLIP BASE FOR BREAK-AWAY LUMINAIRE SUPPORTS

by

Thomas C. Edwards
Assistant Research Engineer

Research Report Number 75-10
Supplementary Studies in Highway Illumination
Research Project Number 2-8-64-75

Sponsored by
The Texas Highway Department
In Cooperation with the
U. S. Department of Transportation
Federal Highway Administration
Bureau of Public Roads

August 1967

TEXAS TRANSPORTATION INSTITUTE
TEXAS A&M UNIVERSITY
COLLEGE STATION, TEXAS

FOREWORD

The information contained herein was developed on Research Project 2-8-64-75 entitled "Supplementary Studies in Highway Illumination," which is a cooperative research project sponsored jointly by the Texas Highway Department and the U. S. Department of Transportation, Federal Highway Administration, Bureau of Public Roads. The broad objective of this project is to (a) study methods to evaluate and compare continuous highway illumination systems, (b) study the visibility characteristics for high level lighting and driver requirements for rural interchange lighting, (c) evaluate contemporary luminaire supports for safety and develop break-away bases to enhance roadside safety. This report covers the specific objective of developing a break-away base for luminaire supports.

ACKNOWLEDGEMENTS

The concept of the slip base developed in this research was conceived in discussions with Mr. Leon Hawkins of the Texas Highway Department, concerning ideas for a multi-directional base for small roadside signs. These discussions were in connection with sign support research in progress before the inception of this particular research effort.

The efforts of Mr. John Finneran, who conducted the laboratory investigations, are gratefully acknowledged. Special thanks go to Mr. James Byram, Mr. Floyd Godwin, Mr. James Mahle, Mr. James Bradley, and Mrs. Diantha Langley for their assistance in the conduct of the crash tests.

The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the Bureau of Public Roads.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

MULTI-DIRECTIONAL SLIP BASE FOR BREAK-AWAY LUMINAIRE SUPPORTS

CHAPTER I

INTRODUCTION

1.1 Background

Under present illumination practices, luminaire supports are located close to the traveled way. These supports are often hit by vehicles that are forced to leave the highway for various reasons. National statistics from the completed portions of the Interstate System show that four percent of the fatal single vehicle accidents involving roadside obstacles along such roads are with luminaire supports.[1] Obviously steps must be taken to eliminate these hazards to safety. The research initiated under this study has attempted to define the hazard potential of existing supports and to investigate means to eliminate it.

1.2 Relation of Other Project Research Reports

In order to determine the severity of collisions with the types of supports presently in use, a "state-of-the-art" investigation was initiated as an objective of this research. Rowan and Kanak have reported the results of 12 full-scale crash tests on six different combinations of supports and bases.[2] This study revealed the severity of accident that can be expected with the supports and bases tested. The tests showed that the type of base that would break away under the impact of a colliding vehicle produced the least severe collision. Furthermore, it was demonstrated that in collisions involving break-away base supports the low-speed impact presented the most concern. This concern is of the secondary collision of the support post with the vehicle, which occurred only at low speeds. The severity of this secondary collision was minor, however, when compared with the primary collision with a fixed base support.

The researchers found that an additional input was required to fully explore the concept of break-away luminaire supports. A technique was needed which could be used to evaluate the effects of the various support parameters on the motion of the support. Consequently, a mathematical model was formulated and verified which could be used to predict the support post trajectory. Texas Transportation Institute Research Report 75-9 documents this phase of the project.[3]

1.3 Need for the Multi-Directional Slip Base

Due to the placement of some luminaire supports, they are subject to collisions from all directions. It is, therefore, desirable to employ a base which has multi-directional break-away characteristics. The break-away devices tested previously in this research project have been of the frangible type; i.e., constructed of materials that fracture under impact loads, and possess the desired multi-directional properties. Various types of bases which do not require frangible materials have been developed by other investigators. These bases derive their break-away features through the frictional resistance between two clamped plates. (See Appendix A for details.) The bases can be termed slip bases. Tests conducted by the General Motors Proving Grounds,[4] and the Road Research Laboratory[5] in England, have proved the feasibility of this concept.

While the frangible and slip bases are, in general, satisfactory, it is the author's opinion that they have disadvantages. The concept of the frangible base is to destroy the base during the collision. If the design functions correctly, the base must be replaced to return the support structure to service after a collision. Obviously an inventory of bases must be maintained with its attendant costs. Slip bases do not require replacement since they are not destroyed in performing their function. However, in the concept developed by General Motors and the Road Research Laboratory, certain details of construction require specialty items which could affect their initial cost as well as maintenance costs. With these thoughts in mind, this report documents the efforts made toward the development of a new non-frangible base using the slip principle.

1.4 Research Objective

The objective of this research was to develop a slip base that is feasible, has multi-directional properties, and is easily adaptable to field modification of existing luminaire supports.

C H A P T E R I I

CONCEPT AND DEVELOPMENT

2.1 Concept of the Slip Base

The base discussed in this report is referred to as the triangular slip base. The name is derived from the basic geometry of the base bolt placement. As shown in Figure 1 (a), the base bolts are placed in slots at the apexes of an equilateral triangle. This configuration produces a base, which by its symmetry, exhibits identical force-slip characteristics for forces applied in any one of the six 60° segments.

The base is composed of two identical plates. Each plate has slots at the apexes of the triangle. The bottom plate is rigidly attached to the foundation. The top plate is secured to the luminaire support post. Bolts are placed in the slots and tightened to provide the clamping forces. Figure 1 (b) illustrates the behavior of the base under applied load. Stage 1 is the condition before slip occurs. In Stage 2, the top plate is forced by the applied load to move with respect to the restrained bottom plate. This movement causes the bolts, at 1 and 2, to move laterally. This lateral bolt movement is caused by the scissor action of the slots as the top plate slips over the bottom plate. The bolt at 3 is forced out of its slot in the direction of movement. Slip continues until the bolt movement exceeds the limits of the slots as shown in Stage 3. The resistance to slip is composed of the friction of the bolts against the surfaces of the slots, and the bearing of the bolts in the slots. The angle of the slot, angle ϕ in Figure 1 (a), influences the joint slip resistance as does the line of action (angle of incidence) of the applied force. The influence of these two variables was studied in the laboratory using model bases.

Figure 2 shows an exploded view of a prototype base illustrating the arrangement of washers in the assembly. The presence of washers on the faying surfaces of the plates insures consistent friction values and guards against gouging by the plate edges.

2.2 Laboratory Investigation

Small bases were used in the laboratory investigation to study the effects of base bolt tension, slot angle, and angle of attack on the base performance under dynamically applied loads.

The test fixture used in the tests is shown in Figure 3 (a). The impact load was applied with a pendulum. The pendulum bob, see Figure 3 (b), weighed 33.5 lbs. and had a neoprene rubber cushion on the impact

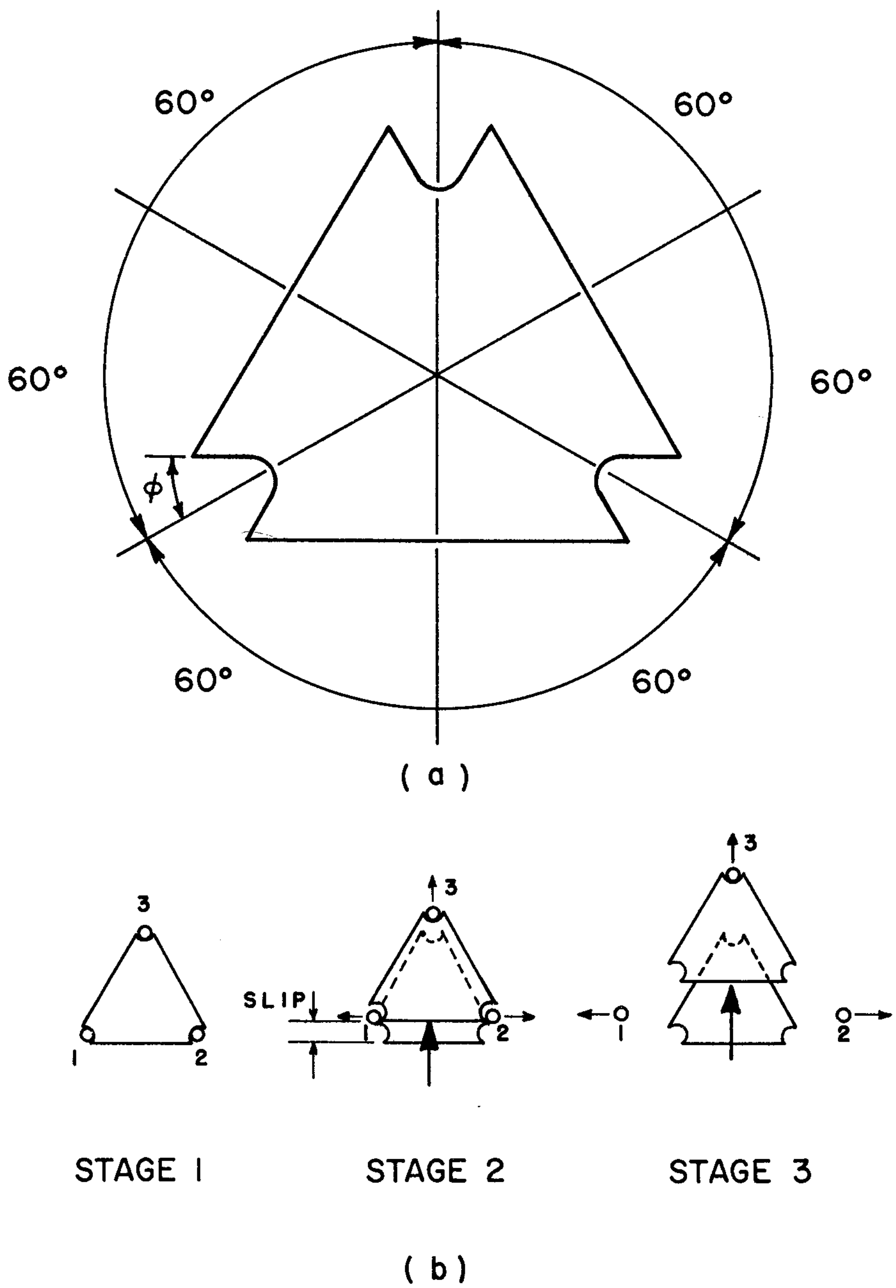


FIGURE 1 — CONCEPT OF SLIP BASE.

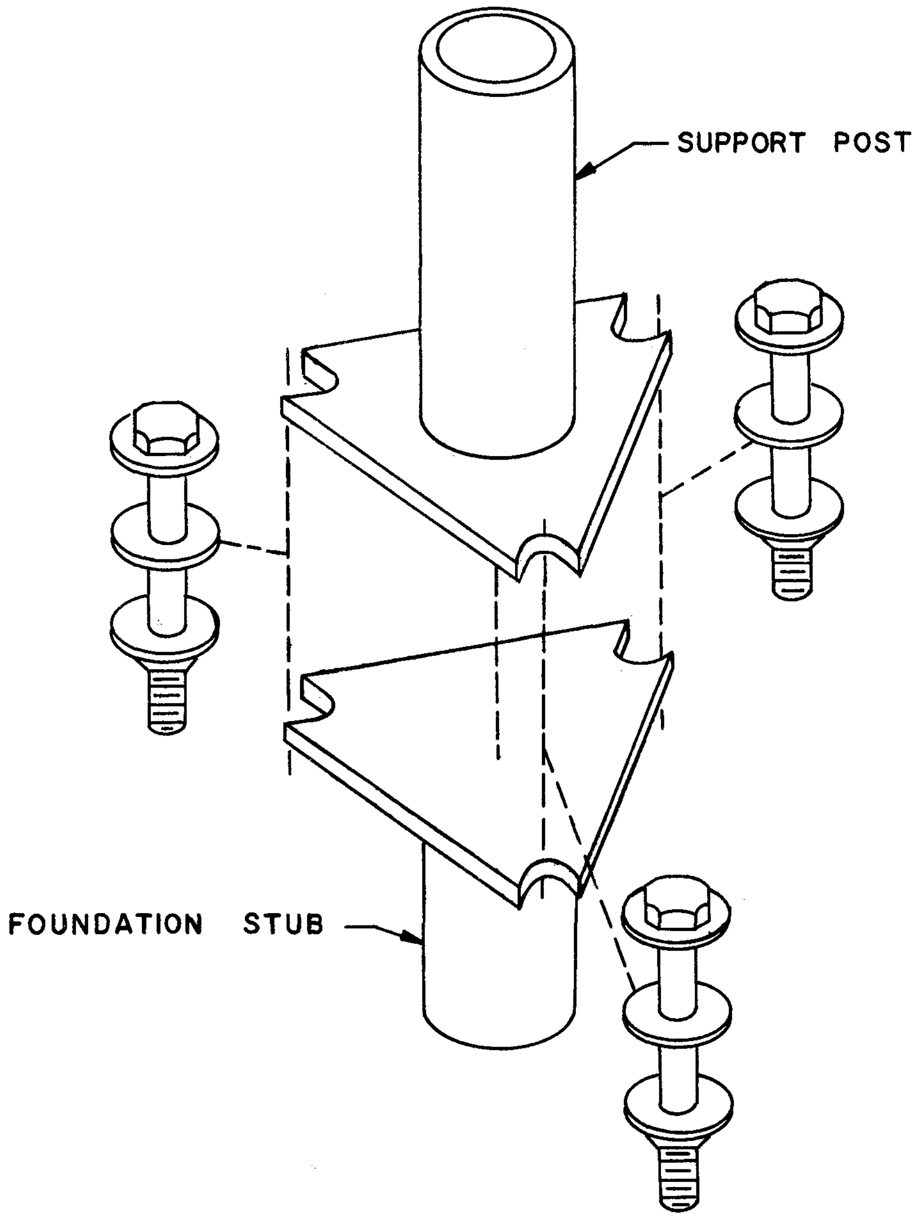
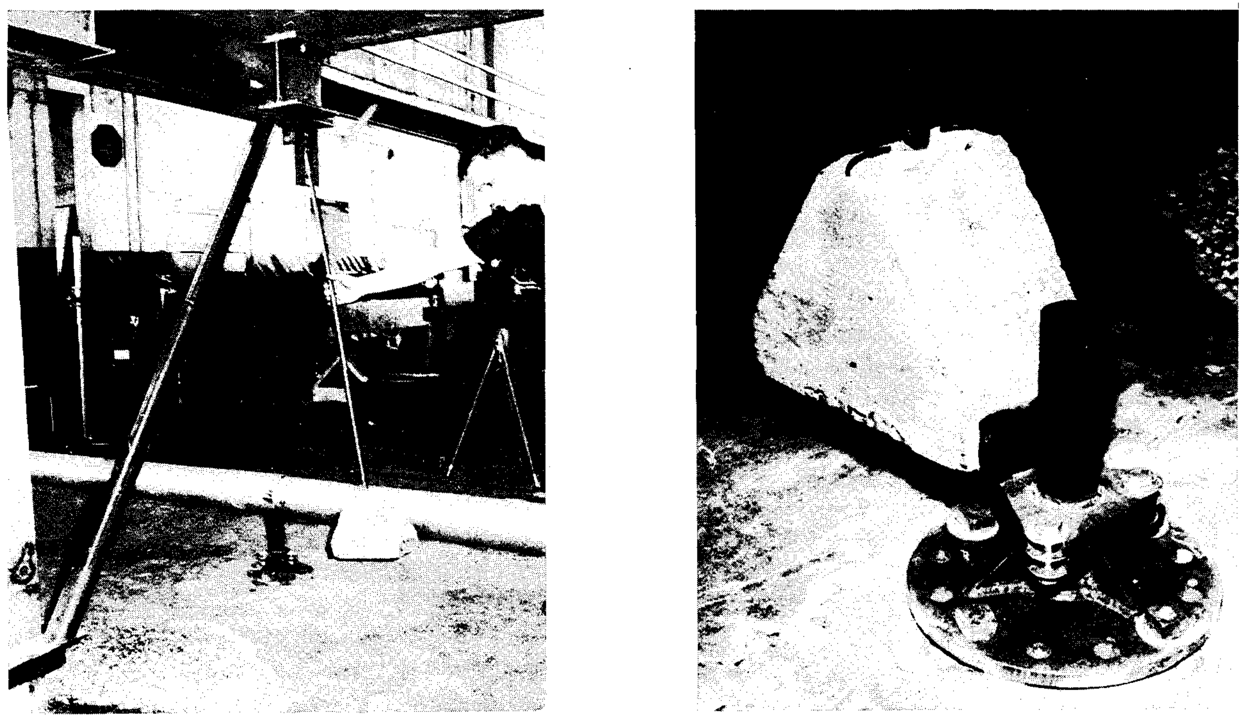


FIGURE 2 -- PROTOTYPE MULTI-DIRECTIONAL BASE.



(a) (b)

FIGURE 3 -- LABORATORY TEST FIXTURE.

face to insure uniform load distribution. The radius of swing could be varied to produce an impact anywhere on the six-inch stub post mounted on the base. The bases to be tested were mounted on a universal foundation plate which was bolted to the laboratory floor. As shown in Figure 3 (b), the plate had mounting holes spaced at 30° intervals around the bolt circle. This allowed the base to be rotated to provide different angles of incidence of the applied dynamic force. With this apparatus the multi-directional properties of the bases could be studied.

Plates with slot angles of 20, 25, and 30° were tested. Figure 4 shows the bases used. The clamping force between the base plates was controlled by torqueing each bolt to a prescribed tension. The base bolts used in the tests were instrumented with strain gages and hence could be precisely torqued.

The dynamic slip resistance of the bases was measured by the impulse required to disengage it. The magnitude of this impulse was measured with an accelerometer mounted on the pendulum bob. Since this study was concerned primarily with the relative performance of the different bases, a comparison could be made on the basis of the deceleration of the pendulum bob. The instrumentation used in these tests is listed and described in Table 1.

Each base was tested with the nine combinations of three bolt tensions (50, 100, and 150 lbs.) and three angles of incidence (0, 30, and 60°). The pendulum was dropped from a height of 22 1/2 in. in all tests. The point of impact on the post stub was 2 7/8 in. above the top surface of the top base plate. The pendulum was released by a solenoid operated latch so that the impact energy was constant for each test.

2.3 Test Results

The tests showed that the slot angle is critical to the performance of the base. In the tests on Bases 1 and 2 (slot angle of 20 and 25°, respectively) with a bolt tension of 50 lb., the base did not activate (separate) under the impact at any one of the three angles of incidence. No attempt was made to force the activation of the base by increasing the pendulum drop height, because of the fear of damaging the instrumented bolts. The failure of the base to activate is attributed to the flat slot angle. The bolts locked up after an initial small amount of slip.

Base 3 performed satisfactorily at 50, 100, and 150 lb. bolt tensions for all angles of incidence. Figure 5 shows the results of the tests on this base. The figure shows the influence of the angle of

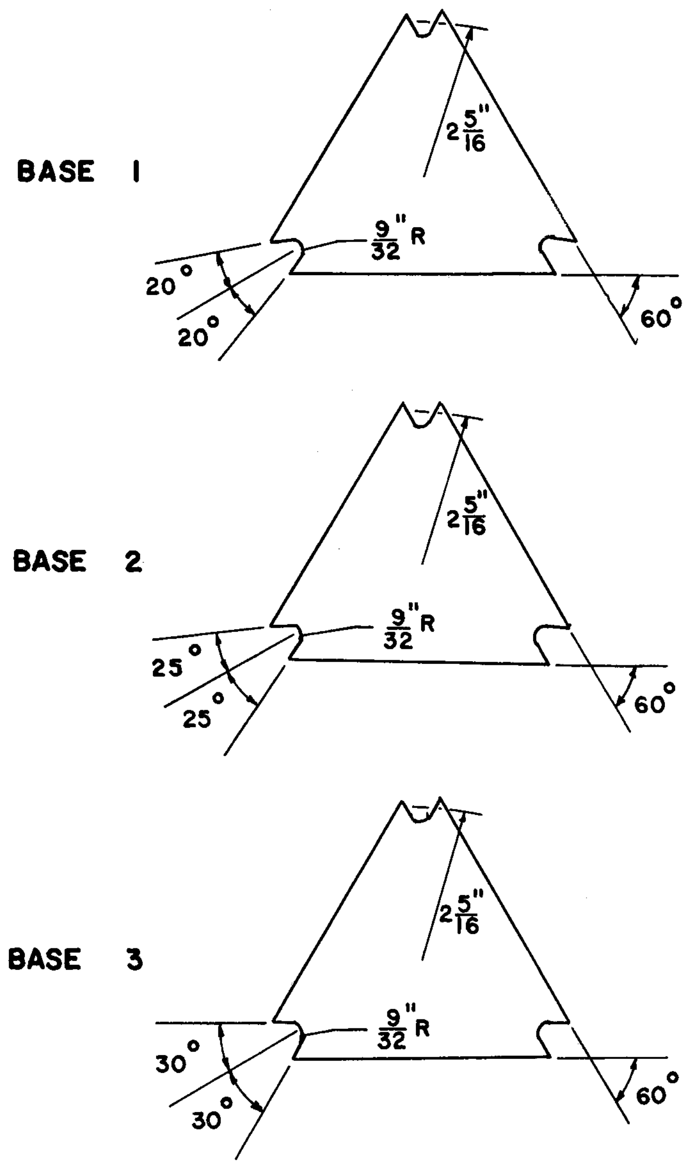


FIGURE 4 -- BASES FOR LABORATORY INVESTIGATION.

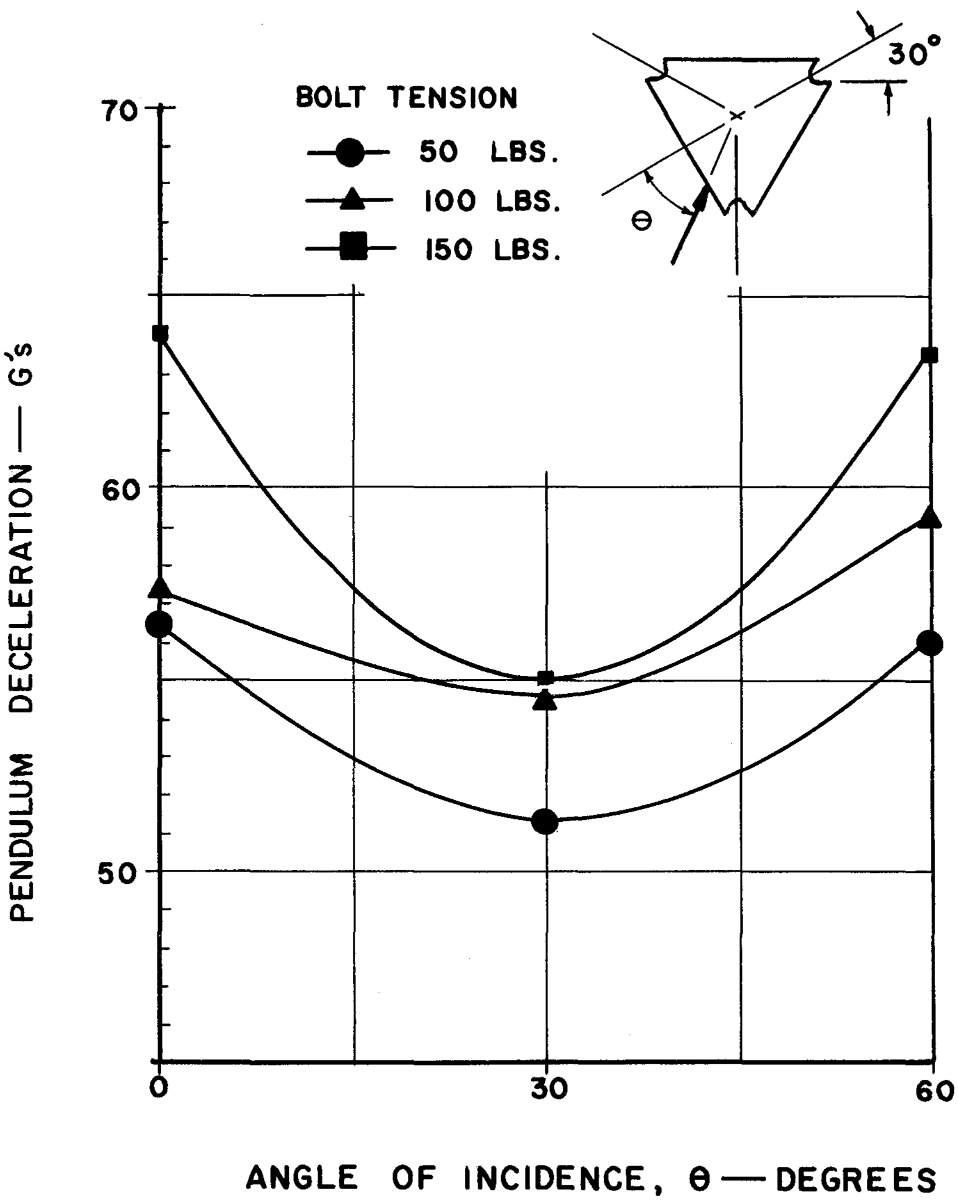


FIGURE 5 -- TEST RESULTS, BASE 3.

TABLE 1--INSTRUMENTATION USED IN LABORATORY INVESTIGATIONS

INSTRUMENT	DESCRIPTION	TO PROVIDE	COMMENTS
Accelerometer.	Endevco Model 2211C with Model 2614 amplifier.	Deceleration of pendulum bob.	Calibration 33 1/3 g/in.
Recorder.	Honeywell Visicorder Model 1508 with M 400-120 optical galvanometer.	Record of accelerometer output.	Record paper speed 30 in./sec.
Strain gaged bolts.	Strainsert Co. 1/2 Internally gaged with full 120 ohm bridge.	Controlled initial tension in base bolts.	#5 5955 μ"/" @12,000 lb. #6 5927 μ"/" @12,000 lb. #7 5997 μ"/" @12,000 lb. all at Gage Factor = 2.00.
Strain Indicator.	Budd Co.	Monitor strain in strain gaged bolts.	

incidence of the applied force. Note that as the base bolt tension was increased the dynamic resistance (indicated by the ram deceleration) increased while the relationship to angle of incidence exhibited the same trends. The multi-directional properties of the base were verified by the similar results at 0 and 60° angle of incidence. The properties are identical in the other five 60° segments, due to the symmetry of the base. Note that the minimum slip resistance occurred at an angle of incidence of 30°.

2.4 Discussion

The tests indicate that the slot angle should be 30°. Angles much larger than this are not practical due to the decrease in washer bearing area. The base had the least resistance to applied load at an angle of incidence of 30° for all bolt tensions used in the tests. The resistance of slip increases with increased bolt tension.

CHAPTER III

FULL-SCALE FIELD TESTS

3.1 Introduction

The laboratory investigations have served to establish the optimum slot angle and angle of collision incidence. In order to validate the concept for service structures, two full-scale crash tests were conducted. The luminaire supports used were standard commercially available units for a 45-foot luminaire mounting height. The tests were conducted with standard passenger automobiles. Test S2 was conducted with a 0° angle of incidence; i.e., the path of the vehicle was normal to the plane of the luminaire arm. In Test S3 the angle of incidence was 30°. Table 2 and Table 3 give the pertinent data for each test. Test S1, while a part of this test series, was used in verification of the mathematical model and is reported in Research Report 75-9.[6]

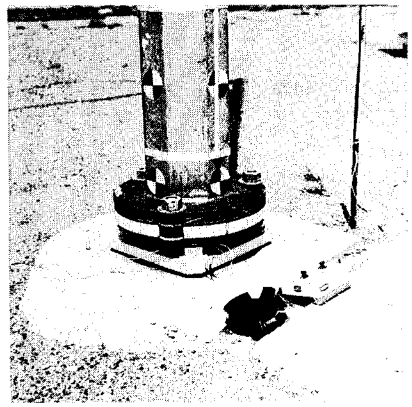
The test instruments employed in each test and their functions are listed in Table 4. The primary data acquisition instruments were the high-speed motion camera and the accelerometers. The data from these instruments were reduced using techniques reported by Olson.[7]

The details of the base used in the tests are shown in Figure 6. A circular plate was used because it produced the minimum bolt circle for the post section employed. A triangular plan form would have required a slightly larger bolt circle.

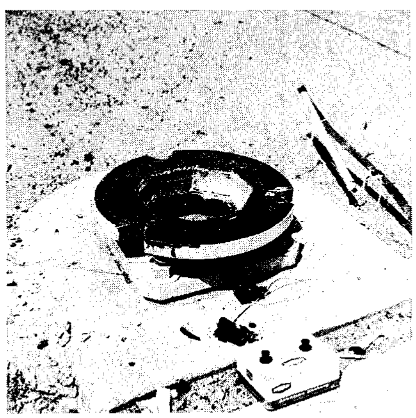
3.2 Test Results

Figure 7 is a summary of the qualitative data derived from observations of Test S2. Figure 7 (a) and (b) views show the support before and after the test. Note in (b) that the support post was bent at the lower luminaire arm-to-post connection. This failure occurred when the post struck the ground. Figure 7 (e) shows the post-collision position of the support post, the base bolts, and the point where the simulated luminaire struck the ground. The luminaire struck behind the foundation base plate and to the left of the vehicle path. The three base bolts, numbered 1, 2 and 3, came to rest in the positions shown. Note that the support post landed with its longitudinal axis approximately in line with the vehicle path.

Figure 7 (c) and (d) views show the damage done to the vehicle. The pole did not contact the vehicle after the initial collision. The vehicle struck the support on a vertical line through the left front headlight. Note that the headlight was not broken and that the total vehicle damage was minor.

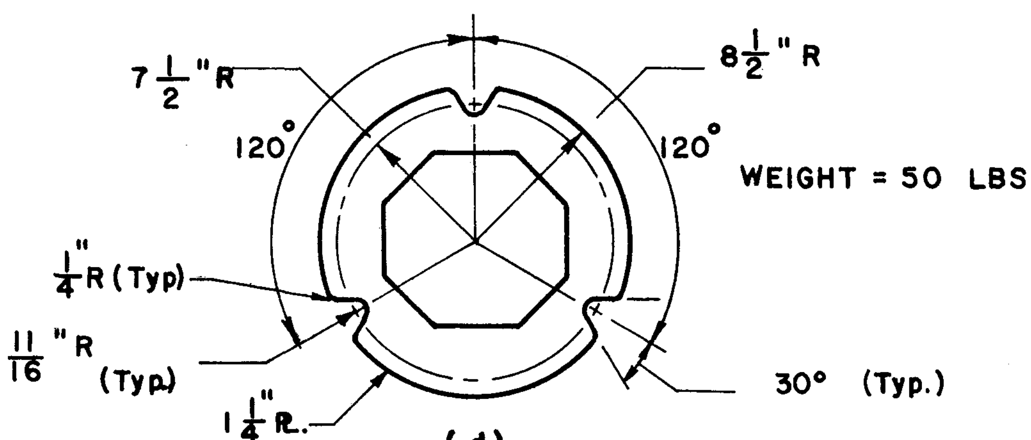


(a)



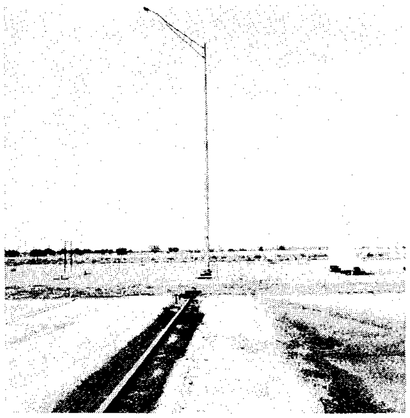
(b)

(c)

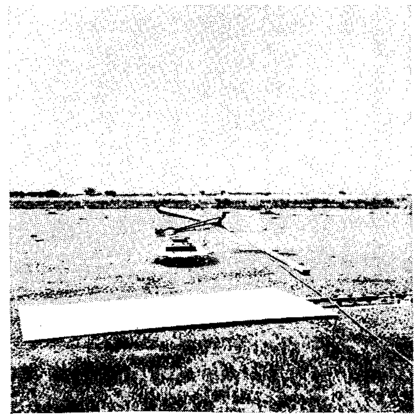


(d)

FIGURE 6 -- DETAILS OF BASE FOR TESTS S2 AND S3.

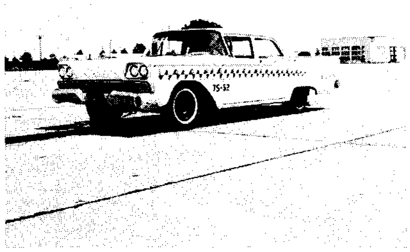


a) BEFORE



b) AFTER

SUPPORT



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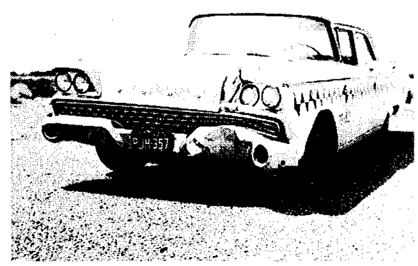
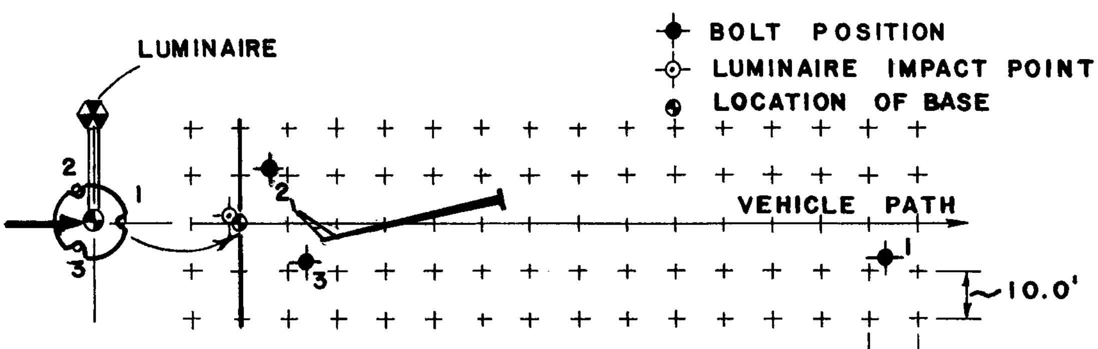


d) AFTER

VEHICLE



e) SUPPORT POSITION AFTER TEST

FIGURE 7 -- TEST S2.

TABLE 2--DESCRIPTION OF TEST S2

Luminaire Support:	(45 ft. mounting height).
(a) Section:	Tapered, octagonal, circumscribed in 4 in circle at top and 9.5 in circle at bottom.
(b) Material:	Steel (ASTM A-245 Grade C) 11 gage. Galvanized to ASTM A-90 Specifications
(c) Luminaire Arm:	10 ft.
(d) Simulated Luminaire:	35 lb. welded steel plate assembly.

Base:

(a) Type: multi-directional triangular (see Figure 6).

(b) Material: A-441 ungalvanized.

(c) Base Bolts: 3-1 1/4" diameter x 4GMB w/1 cap nut each, 6-1 1/4" washers.

(d) Base Bolt Torque: 1000 in./lbs. (approx. 2000 lbs. tension).

Collision Angle of Incidence: 0° (perpendicular to plane of luminaire arm).

Vehicle:

(a) Make and Model: 1959 Ford four-door sedan (3400 lbs.).

(b) Collision Velocity: 56.2 fps (38.3 mph) from film.

Instrumentation: See Table 4.

TABLE 3--DESCRIPTION OF TEST S3

Luminaire Support:	(45 ft. mounting height).
(a) Section:	Tapered octagonal, circumscribed in 4 in. circle at top and 9.5 in. circle at bottom.
(b) Material:	Steel (ASTM A-245 Grade C) 11 gage. Galvanized to ASTM A-90 Specifications.
(c) Luminaire Arm:	10 ft.
(d) Simulated Luminaire:	35 lb. welded steel plate assembly.
Base:	
(a) Type: Multi-directional triangular (see Figure 6).	
(b) Material: A-441 ungalvanized.	
(c) Base Bolts: 3-1 1/4" diameter x 4GMS w/1 cap nut each, 6-1 1/4" washers.	
(d) Base Bolt Torque: 1000 in./lb. (2070 lbs. tension).	
Collision Angle of Incidence:	30° (60° to plane of luminaire arm).
Vehicle:	
(a) Make and Model: 1959 Ford two-door sedan (3500 lbs.).	
(b) Collision Velocity: 52.3 fps (35.7 mph) from film.	
Instrumentation: See Table 4.	

TABLE 4--INSTRUMENTATION FOR TESTS S2 AND S3

Instrument	Description	Location	To Provide	Comments
Piezoelectric Accelerometer.	Endevco Model 2111C with Model 2614 amplifier.	Mounted on left main frame member at location where seat belt attaches.	Deceleration data of crash vehicle.	Inoperative in Test S2.
Strain Gage Accelerometer.	Statham Model A697C.	Mounted on left frame member at location where seat belt attaches.	Deceleration data of crash vehicle.	Inoperative in Test S2.
Recording Oscillograph.	Honeywell Visicorder Model 1508.	Instrument trailer 100 feet from target.	Record of electronic instrumentation.	120 in./sec. paper speed.
Impact Switch.	Tapeswitch Inc. Type "Road Switch."	Attached to target.	Time of impact by recording a mark on recording paper and flashing a bulb for high-speed film.	
Instrumented Bolt.	1 1/4" 7UNC galvanized bolt with 2-arm 120 ohm bridge.	Base plate bolt.	Measure force in bolt due to initial torque.	Used in Test S3. Calibration – 24 µ"/" @1000 lbs. with gage factor = 2.0.

TABLE 4--INSTRUMENTATION FOR TESTS S2 AND S3 (Continued)

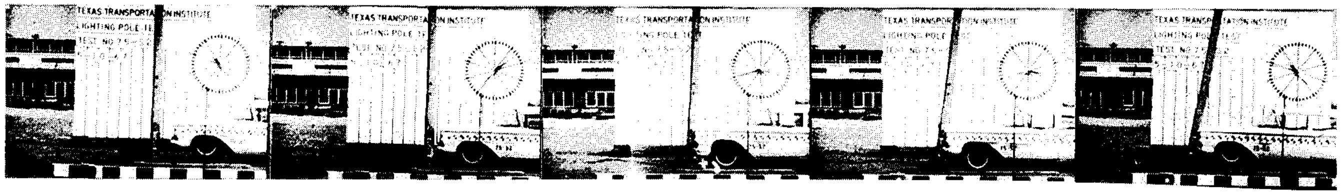
Instrument	Description	Location	To Provide	Comments
High-Speed Motion Picture Camera.	Wollensak, Fastax, WF-3T, 50 mm lens, 16 mm Ektachrome EF Daylight Type 7241 film with high-speed (2R 3000) perforations.	Approximately 100 feet from impact point, line of sight perpendicular to path of crash vehicle.	Crash vehicle time-displacement data.	1000 frames/ sec.
Motion Picture Camera with higher standard speed.	Kodak Cine Special II, 16 mm Ektachrome Commercial Type 7255 film, with No. 85 conversion filter.	Near high-speed camera location described above.	General views of crash test used for copying purposes.	64 frames/ sec.
Standard-Speed Motion Picture Camera.	Bolex H-16 Rex 4, 16 mm Ektachrome Commercial Type 7255 film.	Near high-speed camera location described above.	General views of crash test; panned shots.	24 frames/ sec.
Standard-Speed Motion Picture Camera.	Bell & Howell 70 HR, 16 mm Ektachrome Commercial Type 7255 film.	On boom of lift truck near high-speed camera location described above.	General overhead views of crash test.	24 frames/ sec. Inoperative in Test S2.

Figure 8 shows frames from the high-speed motion picture film of Test S2. The elapsed time after initial contact is shown for each frame. The vehicle remained in contact with the support for 0.146 seconds. Note the position of the luminaire arm in the last two frames. Detailed study of the film indicated that the support rotated clockwise approximately 270° before the arm struck the ground. Data reduced from the film record showed that the change in vehicle velocity was 2.39 mph. Peak deceleration of the vehicle was not obtained due to a malfunction of the accelerometers. The total time of the event was 1.124 seconds.

Figure 9 is a summary of the qualitative data from observations of Test S3. Figure 9 (a) and (b) views show the support before and after the test. Note in (b) that the support post was slightly bent but not to the degree in Test S2. The post-collision position of the support post and base bolts are shown in (e). Note that all three bolts came to rest to the right of the vehicle path. The simulated luminaire struck the ground behind and to the right of the foundation base. The support post landed with its longitudinal axis approximately along the vehicle path. It is important to note the similarity in the post-collision position of the support post in both tests. Despite the difference in the angle of incidence, the support aligned itself with the vehicle path.

Figure 9 (c) and (d) views show the damage to the vehicle. As in Test S2, the support did not contact the vehicle after the initial collision. The vehicle struck the support dead center, crushing the grille and hood. The crushing was not sufficient to damage the radiator and the engine would have remained operative.

Figure 10 shows the sequence of events in Test S3. As in Test S2 the support post rotated clockwise; in this test however the rotation was approximately 220° before the simulated luminaire struck the ground. This occurred at 1.167 seconds. The vehicle remained in contact with the support for 0.185 seconds. Data reduced from the film indicate that the vehicle velocity change was 1.70 mph. The peak deceleration of the vehicle was 33 g's. This value, however, was a spike on the oscillograph record and should not be used as an indicator of collision severity. The accelerometer was mounted on the frame of the vehicle and hence measured only the deceleration of the frame at the point to which it was attached. The deceleration of the vehicle is not a measure of the deceleration of the vehicle occupants. Occupants would respond much slower to an impulse of this type and hence would experience smaller g force. The average deceleration of the vehicle; i.e., the velocity change (ΔV) divided by the duration of the impulse (t_1), is a better indicator of the severity of the collision as far as the passenger is concerned.



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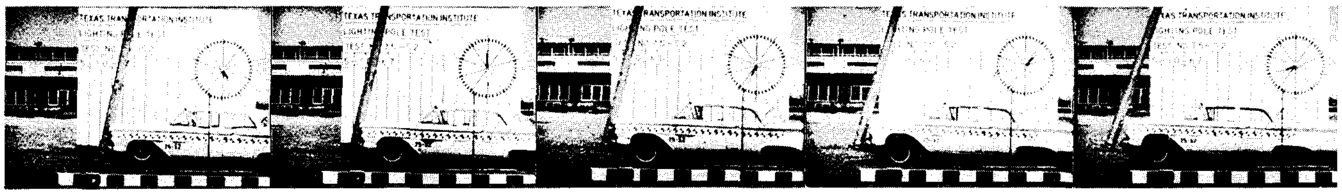

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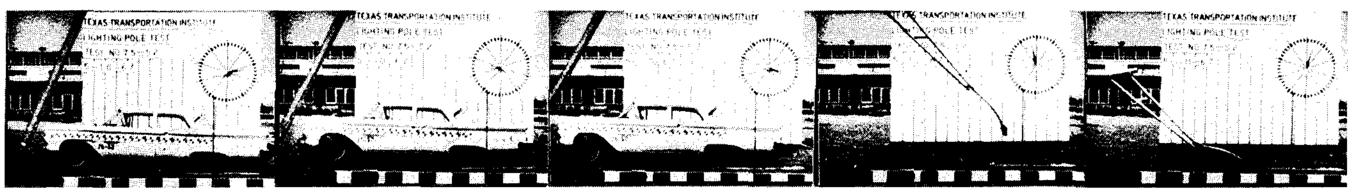
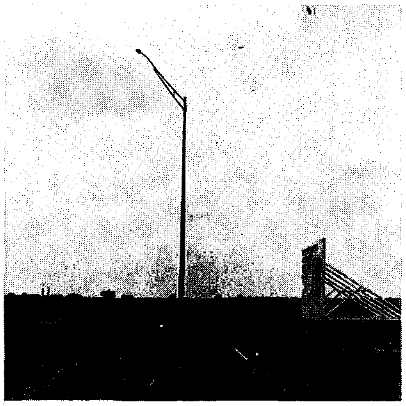
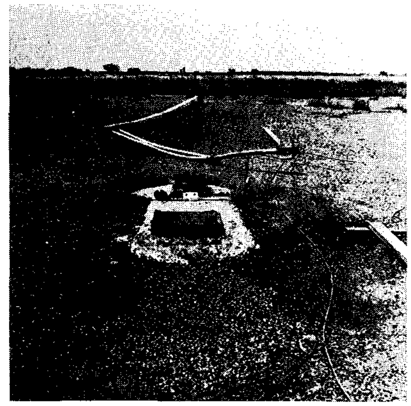


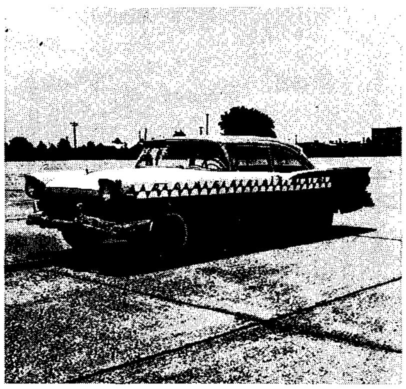
0.187 SEC. 0.207 SEC. 0.228 SEC. 0.958 SEC. 1.124 SEC.

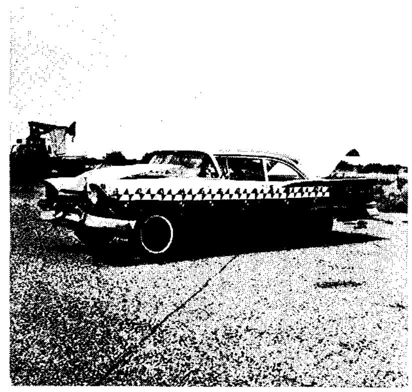
FIGURE 8 -- TEST S2 HIGH-SPEED MOVIE SEQUENCE.



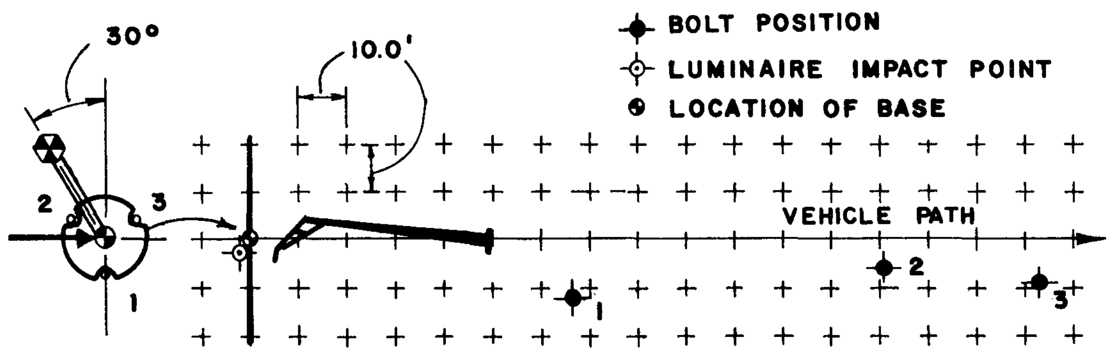


a) BEFORE **SUPPORT** b) AFTER





c) BEFORE **VEHICLE** d) AFTER



e) SUPPORT POSITION AFTER TEST

FIGURE 9 -- TEST S3.

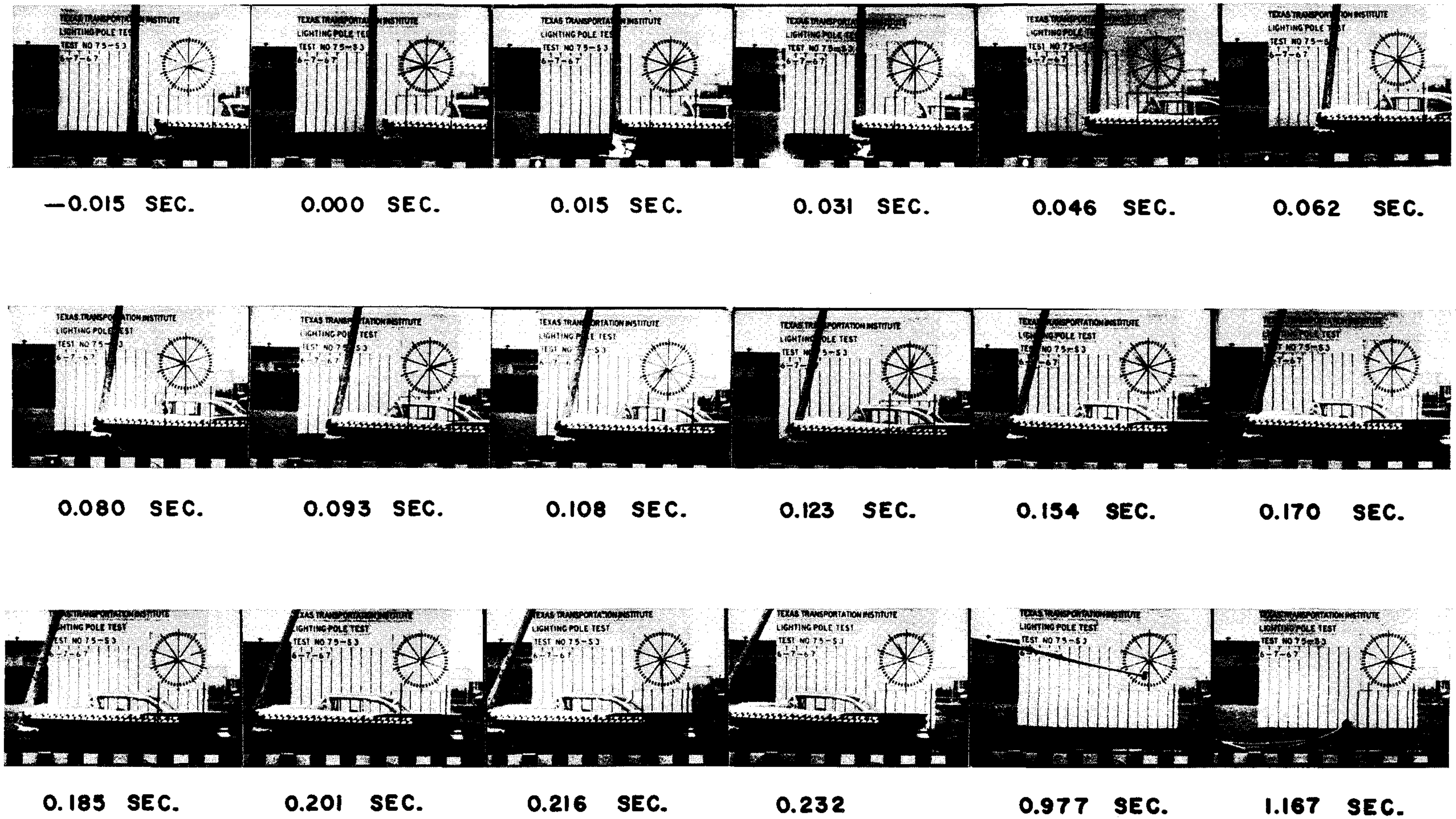


FIGURE 10 -- TEST S3 HIGH-SPEED MOVIE SEQUENCE.

TABLE 5--RESULTS OF DATA REDUCTION

PARAMETER	INSTRUMENT	TEST NO. S2	TEST NO. S3
Initial Vehicle Velocity, (V_o)	Film	56.2 fps, (38.32 mph)	52.3 fps, (35.69 mph)
Final Vehicle Velocity, (V_f)	Film	52.7 fps, (35.93 mph)	49.8 fps, (33.95 mph)
Change in Vehicle Velocity ($\Delta V = V_o - V_f$)	Film Accelerometer	3.5 fps, (2.39 mph) NO DATA	2.5 fps, (1.70 mph) 2.6 fps, (1.71 mph)
Percent Change in Vehicle Velocity, ($\Delta V/V_o$ X 100)	Film Accelerometer	6.23 NO DATA	4.78 4.96
Time Vehicle in Contact with Post, (t_1)	Film	0.146 sec.	0.185 sec.
Total Time of Event, (t_2)	Film	1.124 sec.	1.167 sec.
Average Vehicle Deceleration ($\Delta V/32.2\ t_1$)	Film	0.74 g	0.42 g
Peak Vehicle Deceleration	Accelerometer	NO DATA	33.0 g

C H A P T E R   I V

CONCLUSIONS AND RECOMMENDATIONS

Based on the results of the research reported herein, the following conclusions can be drawn:

1. The triangular slip base is a feasible design for a multi-directional break-away base for luminaire supports.

2. For optimum effectiveness, the triangular base should have a slot angle of 30°.

3. The optimum collision angle of incidence is 30° measured from a line through the geometric center of the triangular plan form (formed by the location of the three base bolts) to the center of a bolt. The support should be orientated such that the most probable vehicle collision path will coincide with this line.

4. The base bolts should be designed to resist the wind load, assuming no preload. In order to keep the base from "walking" under oscillating wind loads, the base bolts should be pre-loaded. For the support tested, the base bolts were torqued to an initial tension of 2000 lbs. each.

5. The test data indicate that the support post will align itself with the path of the colliding vehicle.

For new installations, the bases can be made integral with the support and foundation. Figure 11 suggests a method for modifying existing installations. In this method the slip base is bolted to the original shoe base of the support post. A foundation stub incorporating the triangular base plate is bolted to the existing foundation.

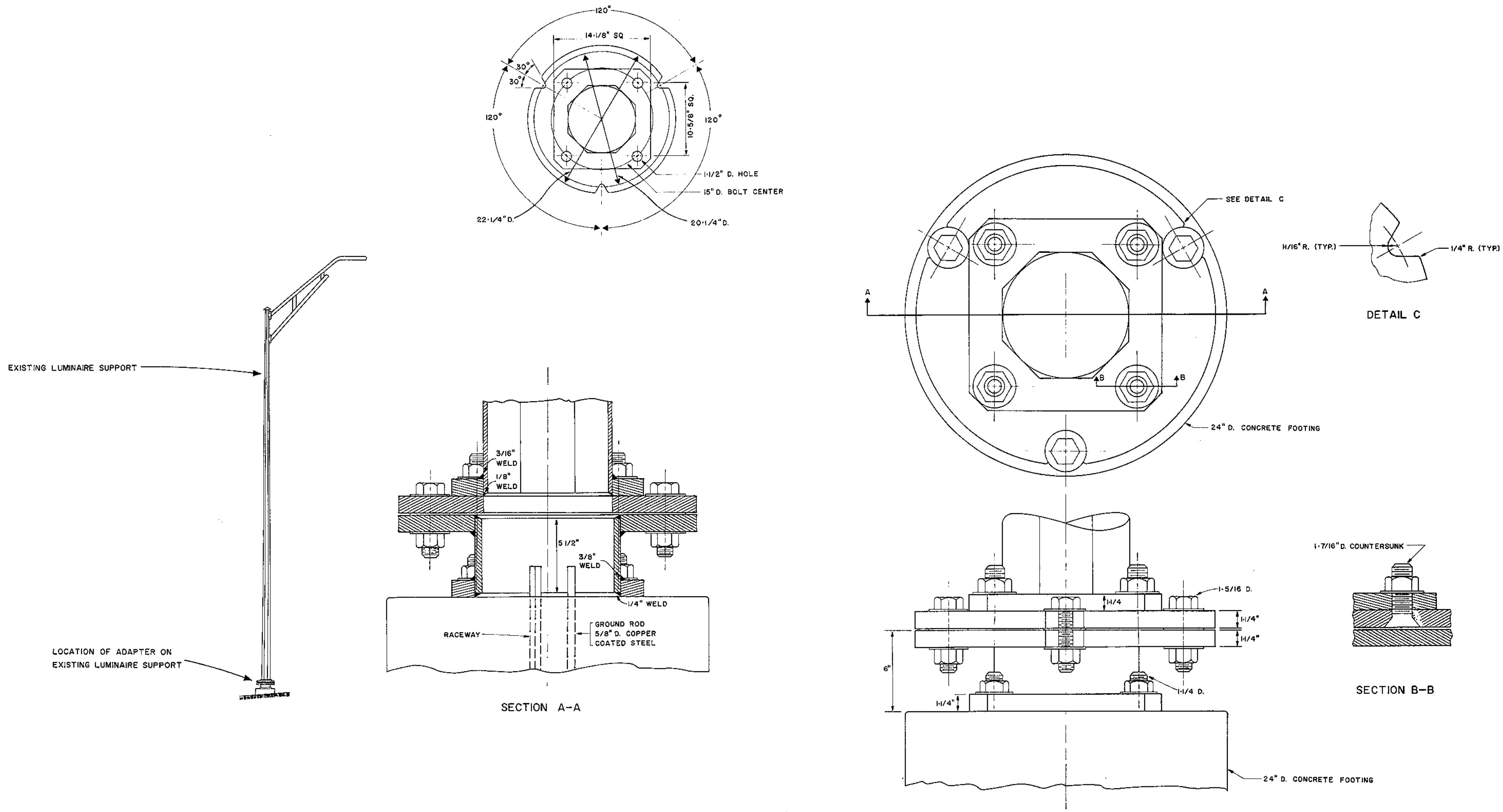


FIGURE 11 -- MULTI-DIRECTIONAL SLIP BASE ADAPTER.

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3. Martinez, J. E., "An Analytical Solution of the Impact Behavior of Luminaire Support Assemblies," Research Report 75-9, Texas Transportation Institute, Texas A&M University, College Station, Texas, August, 1967.

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APPENDIX A

FIGURE A1 -- GENERAL MOTORS SLIP BASE.

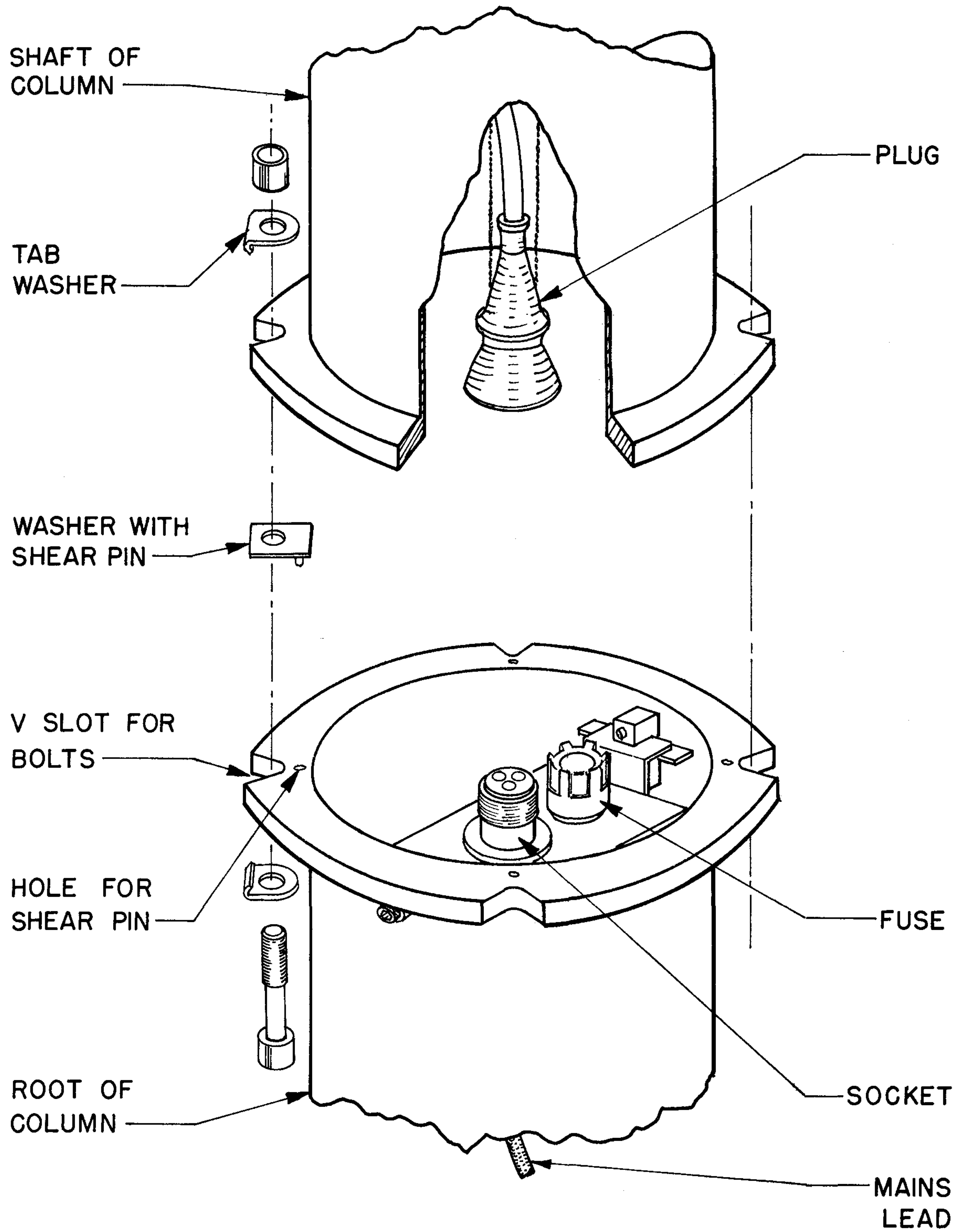

FIGURE A2 -- CAMBRIDGE BASE.