FINAL REPORT

SUPPLEMENTARY STUDIES IN HIGHWAY ILLUMINATION

by

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and

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Supplementary Studies in Highway Illumination
Research Study Number 2-8-64-75

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PREFACE

This final report summarizes the findings of five and one-half years of research in highway illumination on Research Study 2-8-64-75. This research was conducted by the Texas Transportation Institute in cooperation with the Texas Highway Department and the Bureau of Public Roads.

The various phases of the research have been covered in detail in twelve interim reports. These reports, listed as follows, are available from the Texas Transportation Institute upon request.

1. "An Interim Report on a Study of Roadway Lighting Systems," Neilon J. Rowan and Patrick T. McCoy, Research Report 75-1, Texas Transportation Institute, April, 1966.

2. "Interim Report - Impact Behavior of Lighting Standards - I," Neilon J. Rowan, Research Report 75-2, Texas Transportation Institute, Not Published, September, 1966.

3. "An Interim Report on Roadside Sign Visibility," Neilon J. Rowan and Ned E. Walton, Research Report 75-3, Texas Transportation Institute, June, 1967.

4. "Photometric Studies of the Austin Moonlight Tower Lighting Systems," Neilon J. Rowan and Ned E. Walton, Research Report 75-4, Texas Transportation Institute, October, 1966.

5. "An Interim Report on a Study of Disability Veiling Brightness," Neilon J. Rowan, Hans C. Jenson and Ned E. Walton, Research Report 75-5, Texas Transportation Institute, January, 1967.

6. "Photometric Studies of Cutoff Luminaire Designs," Ned E. Walton and Neilon J. Rowan, Research Report 75-6, Texas Transportation Institute, October, 1967.

7. "Interim Progress Report on Supplementary Studies in Highway Illumination," Ned E. Walton and Neilon J. Rowan, Research Report 75-7, Texas Transportation Institute, October, 1967.

8. "Impact Behavior of Luminaire Supports," Neilon J. Rowan and E. W. Kanak, Research Report 75-8, Texas Transportation Institute, October, 1967.

9. "An Analytical Solution of the Impact Behavior of Luminaire Support Assemblies," J. E. Martinez, Research Report 75-9, Texas Transportation Institute, August, 1967.

10. "Multi-Directional Slip Base for Break-Away Luminaire Supports," Thomas C. Edwards, Research Report 75-10, Texas Transportation Institute, August, 1967.

11. "Fatigue Analysis of the Cast Aluminum Base," Hayes E. Ross, Jr., Thomas C. Edwards, and Gerald R. Babb, Research Report 75-11, Texas Transportation Institute, August, 1968.

12. "High-Mast Lighting," N. E. Walton and N. J. Rowan, Research Report 75-12, Texas Transportation Institute, August, 1969.

ACKNOWLEDGEMENTS

It is not possible to thank each individual who has contributed to this research; the writers therefore acknowledge all of the help given.

The research staff has attempted to be responsive to the objectives of the research, while recognizing the sponsors' needs possibly outside of the scope of the objective. The staff accepts all responsibility for shortcomings in this regard, but shares credit for that which is worthwhile with all those who have contributed.

The writers give special thanks to Mr. E. M. Carl, of the Texas Highway Department, who served as contact representative. His expert guidance and counsel was invaluable during the conduct of the research. It has been primarily through his efforts that the results of the research have been implemented nationwide.

The writers would also like to express their thanks for the individuals listed below who have contributed to the conduct of the research and this report.

Patrick T. McCoy
Thomas C. Edwards
Hayes E. Ross, Jr.
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Ernest W. Kanak
J. E. Martinez
William J. Hatchell

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

ABSTRACT

Research Study 2-8-64-75 was initiated by the Texas Transportation Institute to study existing practices in continuous and interchange lighting of highway facilities and to develop improved methods that will reduce glare, improve uniformity of illumination, and offer greater safety to highway users. Studies were conducted to determine the effects of lighting system geometry on illumination, pavement brightness and disability veiling brightness (DVB) produced by various light sources. The lighting systems tested included one-side, median, and staggered lighting systems with 400- and 1000-watt luminaires. The light distribution relationships between these systems is presented. The cutoff type luminaire was also studied and found impractical. Also studied and presented are facts concerning the effects of lighting system geometry on roadside sign visibility. It was found that mounting height definitely has an effect on visibility and legibility of roadway signs. From studies involving the installation of high-mast illumination towers at two interchanges, it was concluded that this was a very effective means of illumination and is superior to conventional systems. Various luminaire support designs were studied, in order to produce a design which would substantially reduce the severity of collisions with luminaire supports. As a result, the slip base design proved feasible for a multi-directional breakaway base for luminaire supports.

SUMMARY

Research Study 2-8-64-75 was initiated in 1964 by the Texas Transportation Institute to study existing practices in continuous and interchange lighting of highway facilities and to develop improved methods that will reduce glare, improve uniformity of illumination and offer greater safety to highway users. Regarding continuous lighting systems, an experiment was performed to determine the light distribution for one-side lighting systems and median or dual-mounted lighting systems. The results suggest that, in order to design the most efficient lighting system to satisfy a given specification, consideration must be given to the relationships between the configuration of the lighting system and the photometric characteristics being used as criteria. Two important factors are uniformity of illumination and minimum amount of illumination. Both the cutoff type luminaire and high intensity discharge lamps were tested. Although both of these innovations had their advantages, they were not strong enough to warrant their installation.

Another important phase was a study of the effects of lighting system geometry on roadside sign visibility. From studying the selected systems, it was observed that increasing mounting heights of 400-watt luminaires from 30 to 40 feet resulted in increased sign visibility. It was also learned that careful attention should be given to the placement of signs in an illumination system. Guidelines were recommended for design of continuous lighting systems for freeway type facilities.

Two full-scale installations of tower lighting at intersections were made to evaluate a complete system of the towers. The two sites were Texarkana, Texas-Arkansas, and San Antonio, Texas. The general observations which resulted from these studies were as follows: (1) the high-mast concept is both technically and economically feasible, and (2) the concept is superior to conventional techniques in providing safe nighttime driving environments in interchanges.

The severity of collisions with luminaire supports on Texas highways indicated a need to determine the impact characteristics of various pole and base mounting designs now in use. The study consisted of full-scale, head-on crash tests of various luminaire support designs. The conclusions indicated that cast aluminum transformer bases reduce the severity of impact most effectively, and cast aluminum inserts, employed to reduce impact severity of the steel transformer bases which are already in service, are adequate for this purpose.

Research Report 75-10 documented the development of a breakaway base for luminaire supports. After laboratory investigations and full-scale field tests on the multi-directional slip base, it was determined that the slip base is a most feasible design for luminaire supports.

TABLE OF CONTENTS

INTRODUCTION

AND

OBJECTIVES

INTRODUCTION AND OBJECTIVES

As substantial mileage of the Interstate Highway System was completed in Texas, the State Highway Department recognized the need for lighting those facilities, especially in the urban areas. However, officials were greatly concerned that the design criteria for roadway lighting had not changed to meet the challenge of the new generation of modern highways. Because of this concern, a research project in roadway lighting was initiated in 1964 by the Texas Transportation Institute and the Texas Highway Department, in cooperation with the Bureau of Public Roads.

Known as Research Study 2-8-64-75, Supplementary Studies in Highway Illumination, the research had as its overall objectives, "the study of existing practices in continuous and interchange lighting of highway facilities and the development of improved methods that will reduce glare, improve uniformity of illumination and offer greater safety to the highway users."

Specifically, the research involved three major areas of concern. They are the following:

1. The establishment of guidelines for efficient and functional continuous lighting systems;
2. The investigation of methods for illuminating interchanges; and
3. The development of methods for improving safety of lighting supports.

A full-scale laboratory approach was taken in most of the research to facilitate subjective, as well as objective, evaluation of lighting systems. This laboratory, located on a large concrete area of the Texas A&M University Research Annex (formerly Bryan Air Force Base), provides an excellent facility for close examination of almost any lighting system concept.

Many of the results from the research were implemented by several states before being formally reported. This report is an effort to coordinate all of the phases of the research, in hopes that it will be useful to anyone involved in the lighting of the nation's streets and highways.

CONTINUOUS LIGHTING SYSTEMS

CONTINUOUS LIGHTING SYSTEMS

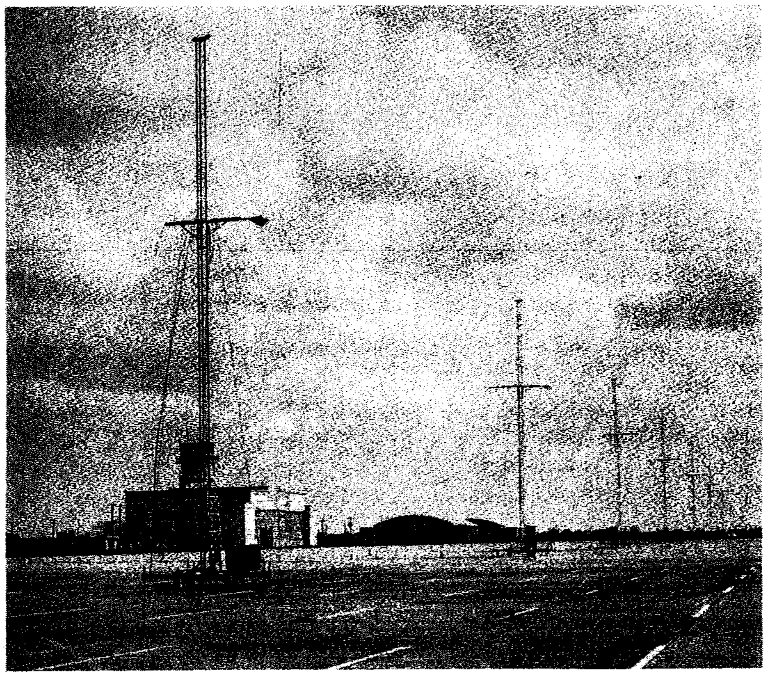
Essential to the accomplishment of the goals of this research is the definition of the relationships among visibility, visual comfort, brightness patterns, light distributions, glare distributions, and the configuration of the lighting system. These relationships have been studied at the Texas A&M Highway Illumination Test Facility. This facility was developed whereby a representative section of roadway lighting could be simulated with complete flexibility in selection of system configuration and illumination design. This permitted careful study of the above cited relationships.

Light Distributions

Roadway luminaires were mounted on ten 60-foot mobile towers which could be adjusted and maneuvered to provide various mounting heights and spacings of the luminaires (Figure 1). These towers were arranged on a large, paved area approximately 500 feet wide by 3500 feet long, where a grid system was laid out with 10-foot longitudinal grid line intervals and 12.5-foot transverse grid line intervals.

The light distributions of the lighting systems were determined by measurements made at each grid point using a GE SL-480A light meter, cosine corrected to give light intensity in horizontal footcandles.

Commercially-available 400-watt and 1000-watt, Type III mercury vapor luminaires were used in this study. Three 400-watt luminaires were obtained from each of four manufacturers, and three 1000-watt luminaires were obtained from each of three manufacturers. The lamps



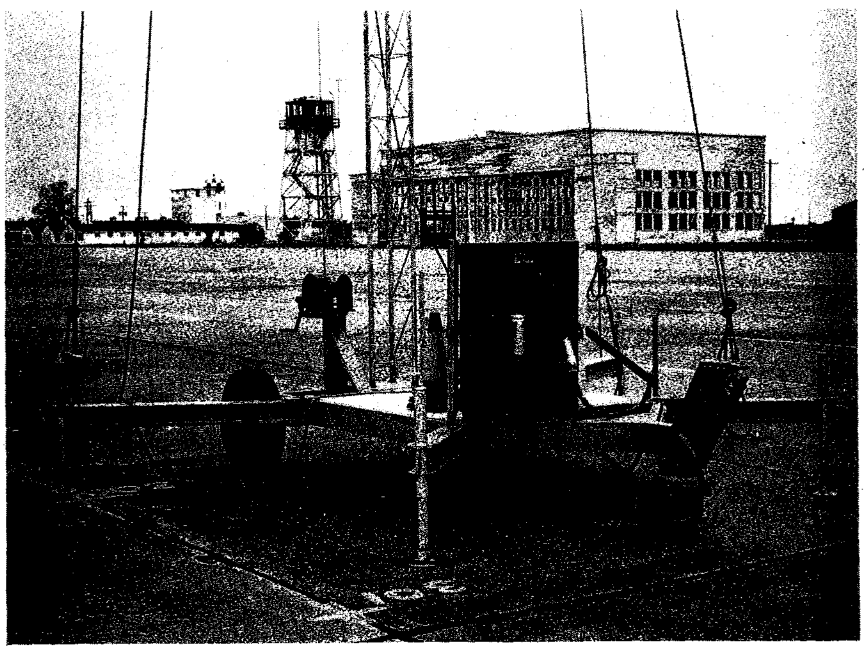


Figure 1. Portable lighting towers.

used in all luminaires were those available on state contract. They were clear mercury vapor lamps with outputs of 21,500 and 57,000 lumens for the 400-watt and 1000-watt units, respectively.

The experimental design provided a determination of the light distribution for one-side lighting systems and median, or dual-mounted, lighting systems, using the three luminaires from each manufacturer. Table 1 summarizes the experimental design for each manufacturer.

Utilizing computer techniques, photometric measures and iso-footcandle curves were developed for the various lighting systems from basic horizontal footcandle data.

The iso-footcandle curves produced by the computer plotting technique provided a means of visualizing the effects of system configuration on the light distribution. Figure 2 illustrates the increase in uniformity of illumination caused by raising a luminaire from a 30- to a 40-foot mounting height. Figure 3 shows the light distributions for several systems. It is significant to note that most of the contour lines within these systems are essentially parallel to the traffic lanes, which indicates that the systems provide uniform lighting for any particular lane.

The effects of system configuration on the resultant light distribution of a roadway lighting system are summarized below. To the illumination expert, these are basic physics phenomena, but to the highway lighting design engineer who is more qualified in applications than theory, these are important considerations in the design process.

1. The initial average illumination on the roadway was inversely proportional to the mounting height and longitudinal spacing of the luminaires, and to the width of roadway considered (Figure 4).

Table 1

Experiment Design

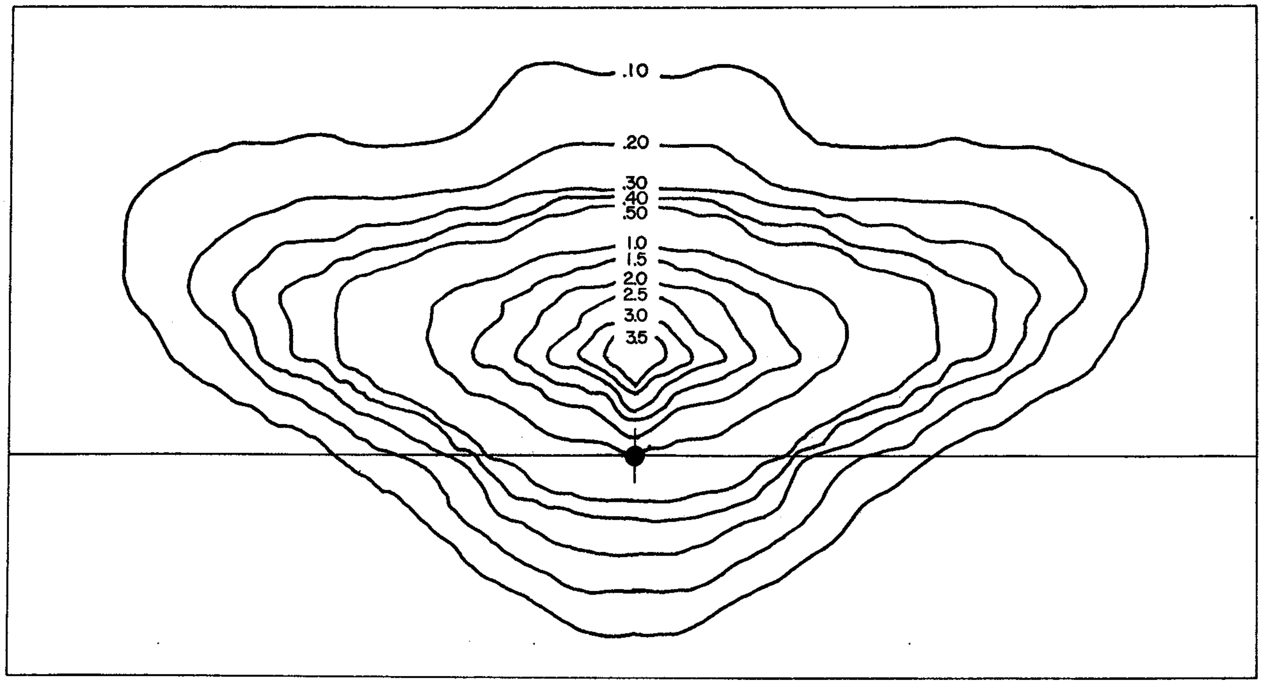
Mounting Height (Feet)	Longitudinal Spacing (Feet)																
	100	120	140	160	180	200	210	220	230	240	250	260	280	300	320	340	360
30	x	x	x	x	x	x	x	x	x	x	x						
40	x	x	x	x	x	x	x	x	x	x	x						
45	x	x	x	x	x	x	x	x	x	x	x						
50	x	x	x	x	x	x	x	x	x	xy	x	y	y	y	y	y	y
60										y		y	y	y	y	y	y

x - 400-watt
y - 1000-watt

Other Parameters In The Experimental Design

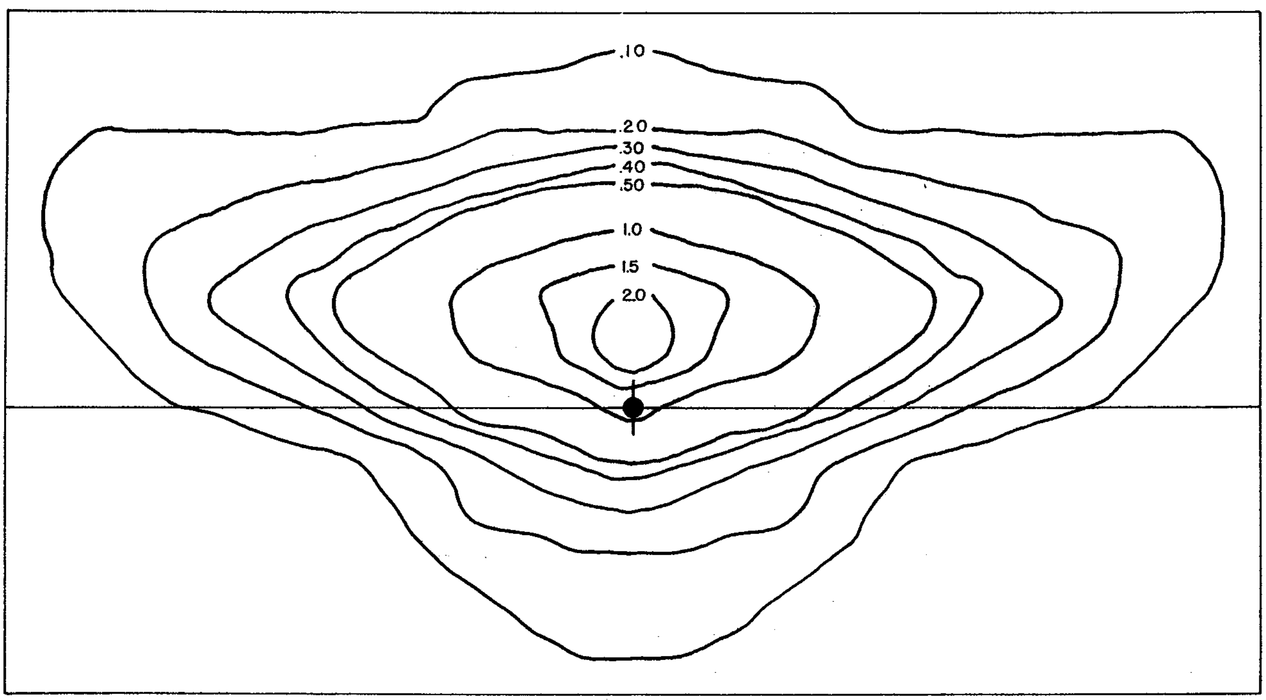
4 Manufacturers, 400-watt
3 Manufacturers, 1000-watt

2 Configurations, One-side and Median
3 Median Transverse Spacings, 10', 20', 30'



ISO-FOOTCANDLE CURVE
SINGLE LUMINAIRE

LUMINAIRE: 400 WATT, TYPE III 4
MOUNTING HEIGHT: 30'



ISO-FOOTCANDLE CURVE
SINGLE LUMINAIRE

LUMINAIRE: 400 WATT, TYPE III 4
MOUNTING HEIGHT: 40'

SCALE: 0 10 20 30 40 50
FEET

Figure 2. ISO-Footcandle charts of individual luminaires.

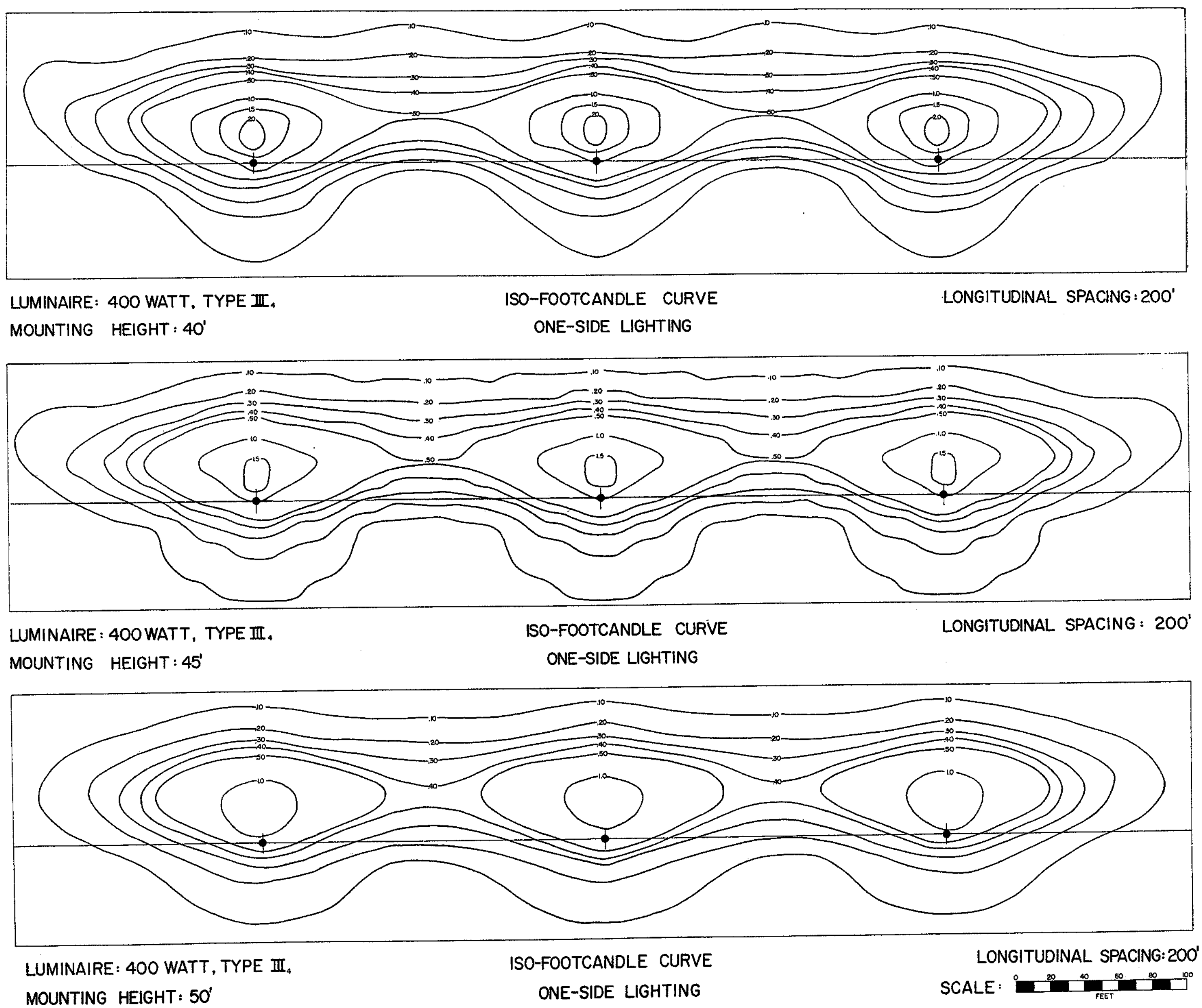


Figure 3. ISO-Footcandle charts of one-side lighting systems.

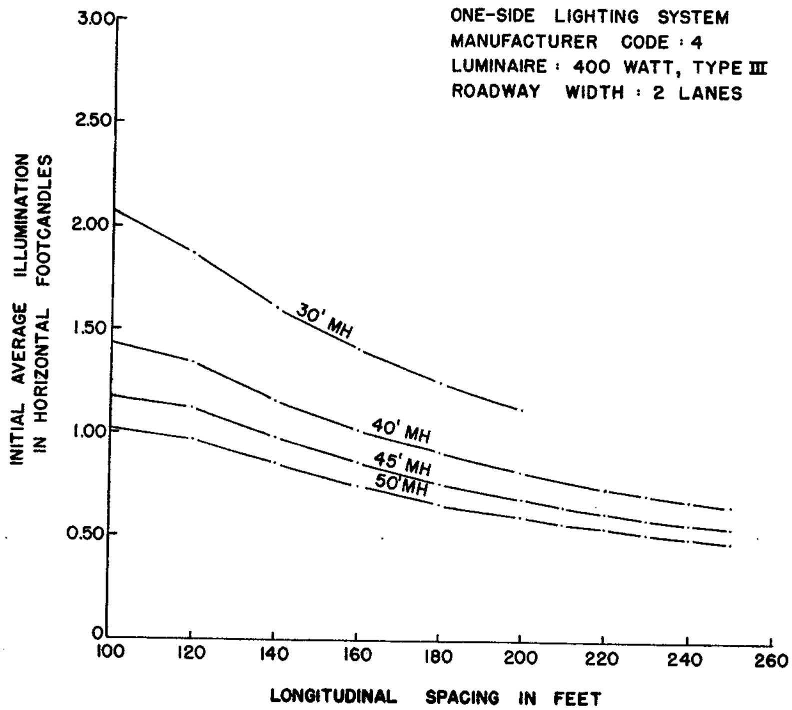


Figure 4a. Initial average illumination vs. longitudinal spacing for different mounting heights.

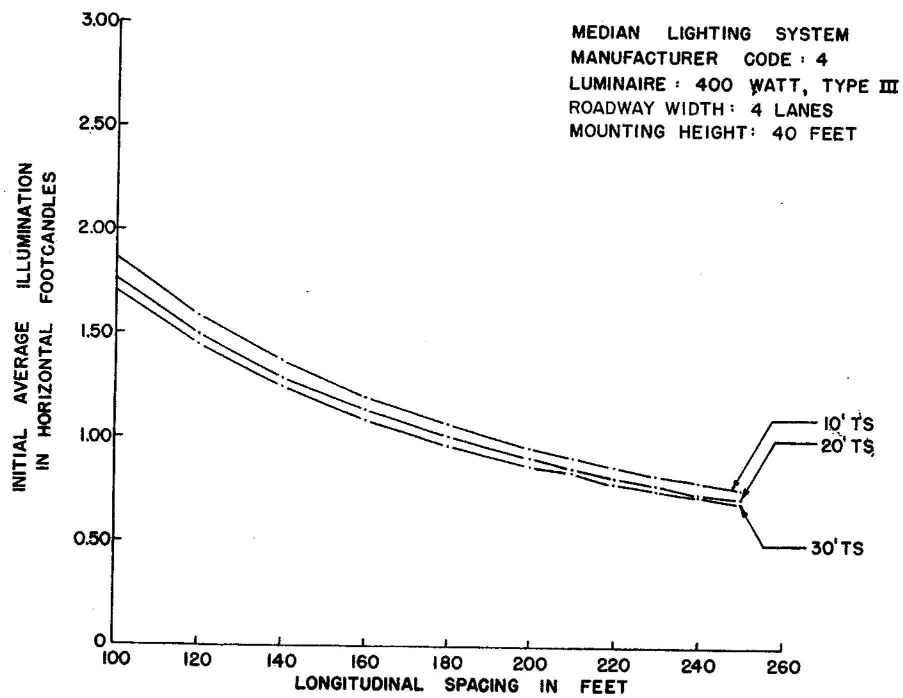


Figure 4b. Initial average illumination vs. longitudinal spacing for different transverse spacings.

Figure 4

2. The uniformity of illumination on the roadway was proportional to the mounting height of the luminaires, i.e., higher mounting heights provide better uniformity (Figure 5).
3. The systems of 1000-watt luminaires provided more illumination and greater uniformity than the 400-watt systems when compared for similar spacing-mounting height ratios.
4. Differences in the amount and uniformity of illumination from luminaires of different manufacturers indicated that the optimum system configuration was dependent upon the make of luminaire used.[2]
5. For higher mounting heights of luminaires, the effect of roadway width on uniformity of illumination was less (Figure 6).
6. For all practical configurations (mounting height and longitudinal spacing combinations) the initial minimum illumination was proportional to the mounting height. In other words, the area of coverage for a given initial minimum illumination was increased.

These results suggest that, in order to design the most efficient lighting system to satisfy a given specification, consideration must be given to the relationships between the configuration of the lighting system and the photometric characteristics being used as criteria.

This research has indicated that uniformity of illumination is a very important factor in roadway lighting design. Visual evaluations of these systems have suggested that any reduction in visibility due to a lower average illumination can usually be compensated for by an

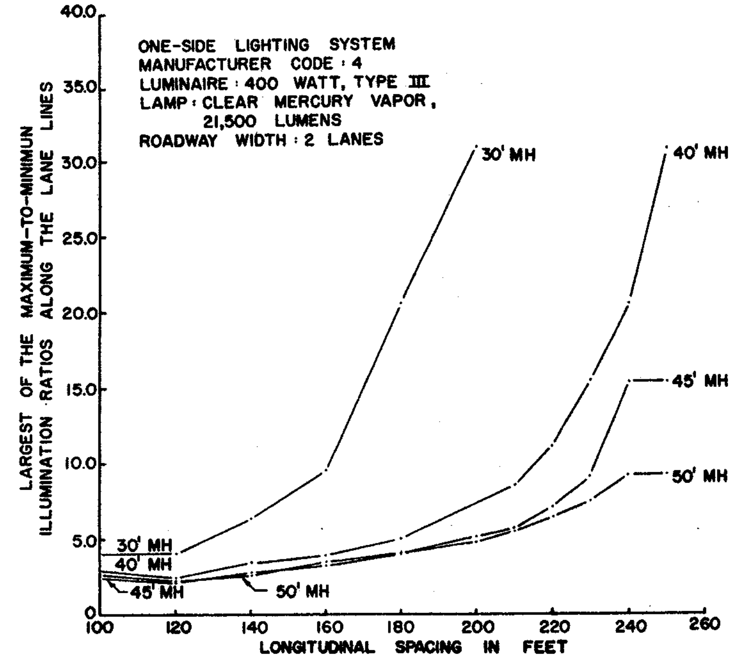


Figure 5a. Ratio of maximum to minimum illumination vs. longitudinal spacing for different mounting heights.

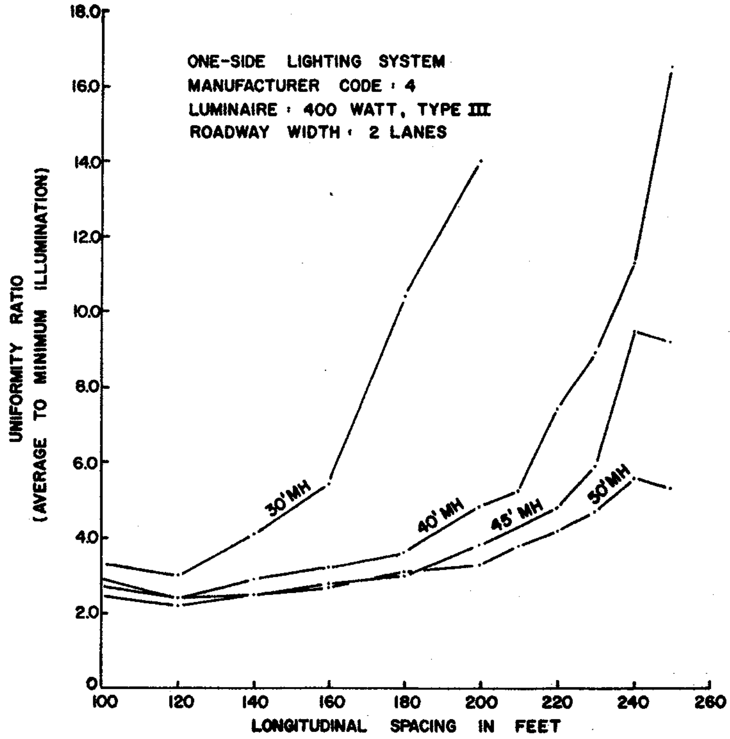


Figure 5b. Uniformity ratio vs. longitudinal spacing for different mounting heights.

Figure 5

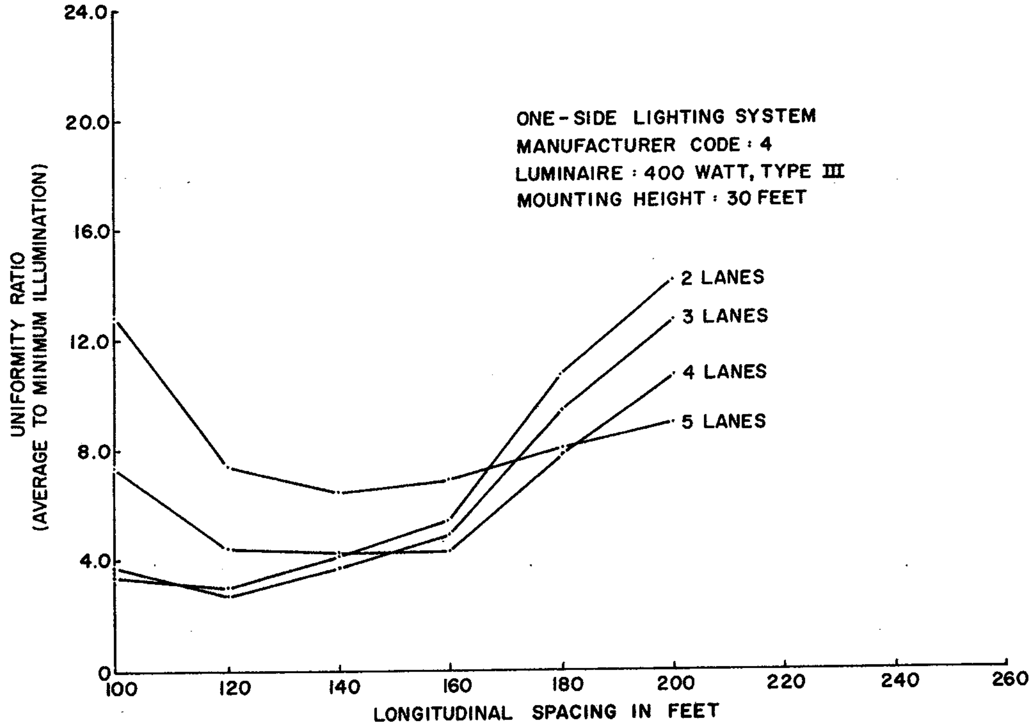


Figure 6a. Uniformity ratio vs. longitudinal spacing for different roadway widths.

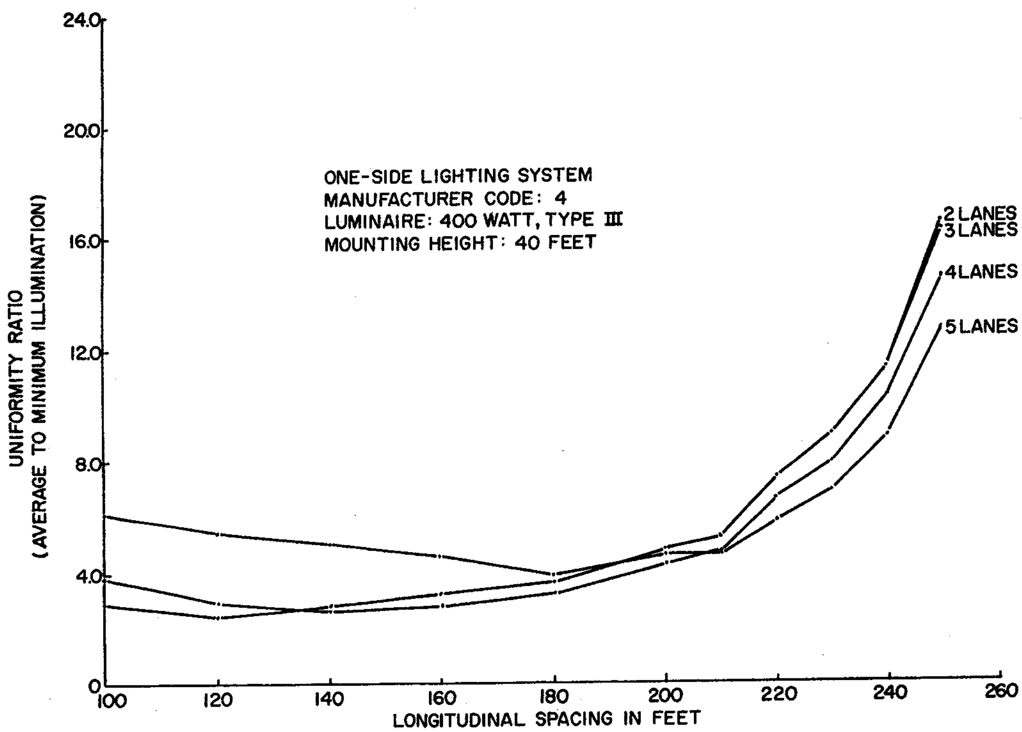


Figure 6b. Uniformity ratio vs. longitudinal spacing for different roadway widths.

Figure 6

apparent increase in visibility due to improved uniformity of illumination, as in the case of systems with luminaires at higher mounting heights. This research also suggests that adequate visibility can be obtained at lower average intensities than are currently specified in design criteria, and that more emphasis should be placed on the minimum amount of illumination and the uniformity, such as by specifying a ratio of the maximum to minimum illumination.

To enable others to apply the photometric data obtained in this research, summary tabulations of the photometric characteristics for several different lighting systems have been prepared and are furnished by the Texas Transportation Institute upon request. From these tables the engineer can readily select the designs that satisfy given criteria for a particular lighting project. A cost comparison can then be made to determine the most economical of several systems providing acceptable photometric characteristics.

Pavement Brightness and Disability Veiling Brightness (Glare) Distributions

One important phase in the development of design criteria for economical and functional roadway lighting was a study of the effects of lighting system geometry on pavement brightness and disability veiling brightness (DVB) produced by various light sources. Such a study was conducted with specific objectives of (1) determining the pavement brightness and DVB of selected roadway lighting systems of 1000-watt Type III luminaires and (2) determining the effect of mounting height on pavement brightness and DVB for 400- and 1000-watt Type III luminaires. The lighting systems tested included one-side, median, and staggered lighting systems with 400- and 1000-watt luminaires.

For the one-side lighting systems, the 400-watt luminaires were mounted on five portable towers. The towers were spaced longitudinally, 165 feet for the 30-foot mounting height and 230 feet for mounting heights of 40, 45, and 50 feet. The luminaires were positioned over the edge of the left lane and were tilted upward vertically to their maximum adjustment on a horizontal mast arm to provide illumination over the entire roadway of six 12.5-foot lanes. The 1000-watt luminaires were mounted on the same towers on longer arms, positioned five feet over the first lane. The longitudinal spacing was 300 feet for both the 50- and 60-foot mounting heights.

For the median lighting systems, two luminaires were mounted back-to-back on a single support with a spacing of 12 feet between the 400-watt luminaires and 22 feet between the 1000-watt luminaires. These luminaires were adjusted for lateral projection of light, as in the one-side system, with the same spacings and mounting heights as used in the one-side system.

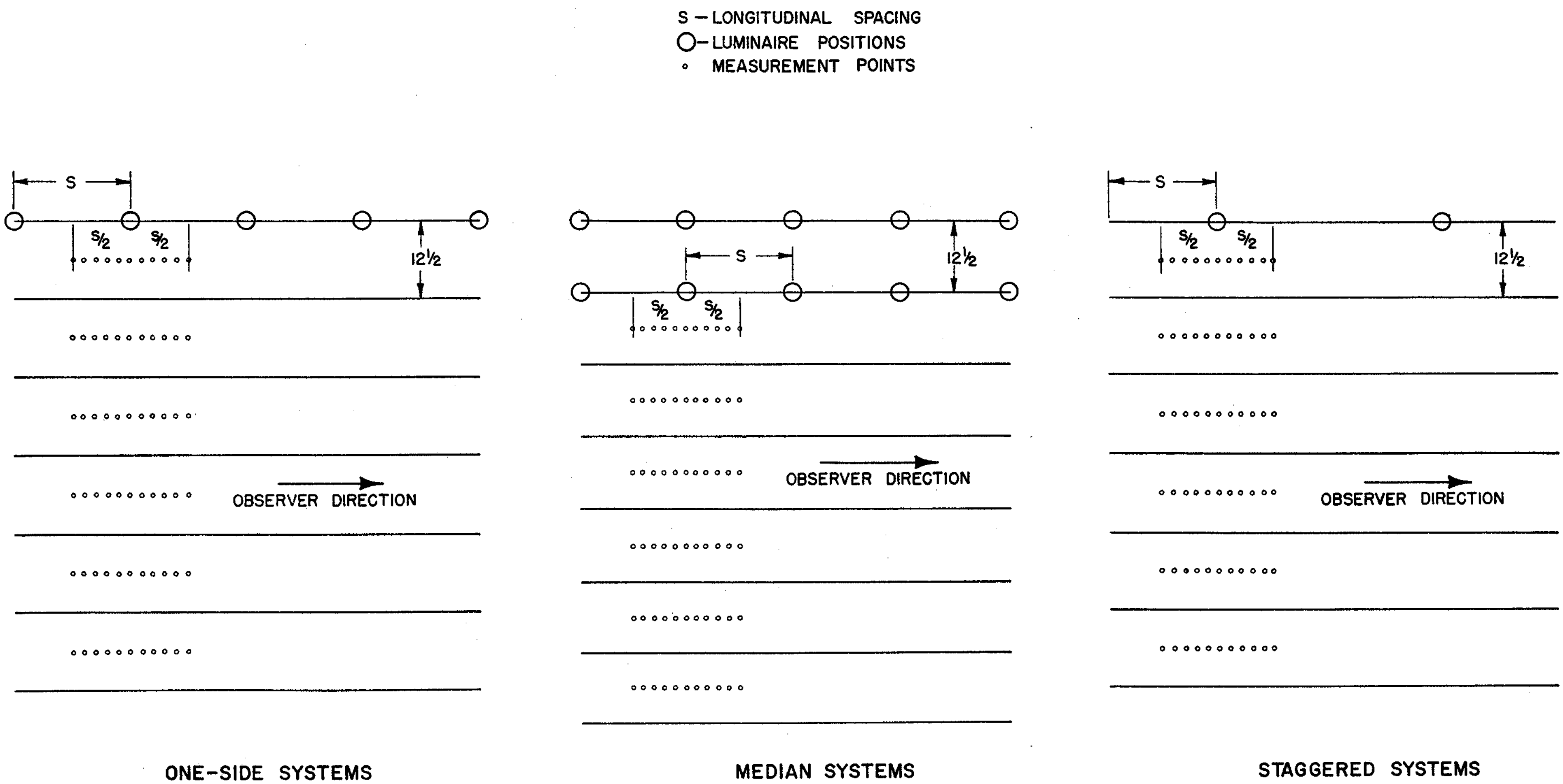
For the staggered lighting systems, five towers were arranged in a staggered pattern along a roadway 75 feet wide for the 400-watt luminaires and 100 feet wide for the 1000-watt luminaires. The longitudinal spacing was 200 feet for the 400-watt luminaires at mounting heights of 30, 40, 45, and 50 feet and was 250 feet for the 1000-watt luminaires at heights of 50 and 60 feet. Overhang was the same as in the one-side system.

For each system, pavement brightness and glare readings were taken along the center of each of six lanes at 10-foot intervals, starting and ending midway between the second and third luminaires. The second luminaire was always at the center of the line of measuring stations, and always to the left of the roadway as the measuring instrument was aimed down the roadway (Figure 7).

A summary of the findings of this study is given below:

1. Systems with luminaires in one-side and median mounting configurations produce approximately the same patterns of DVB. The intensities of DVB are smaller for the median than for the one-side configurations.
2. Distribution of DVB for different mounting heights within the same configuration is similar, but intensities of DVB vary, the greater intensities observed for the lower mounting heights.
3. Intensities of DVB and pavement brightness are greater for 1000-watt luminaire systems than for corresponding 400-watt luminaire systems.
4. Fluctuation of DVB is greater for the 400-watt systems than for the 1000-watt systems.
5. For any of the 1000-watt systems the level of DVB appears to be low enough not to be a critical factor in view of the high pavement brightness produced by the systems.

Further studies should be conducted to investigate measurements of representative tasks, including measurements of task brightness,



LAYOUT OF THE TEST SITE

Figure 7

pavement brightness, and DVB to determine task contrasts and loss of visibility caused by DVB for the systems under consideration.

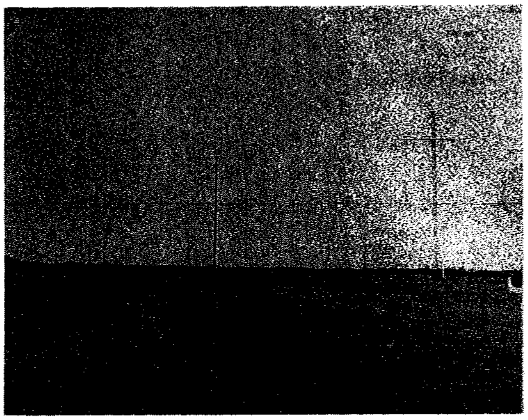
It is evident that ratings for the effectiveness of roadway lighting in producing good visibility conditions are needed. Relative visibility ratings based on the requirement of the visual tasks must be developed to aid in the evaluation of lighting systems.

Photometrics of Cutoff Luminaires

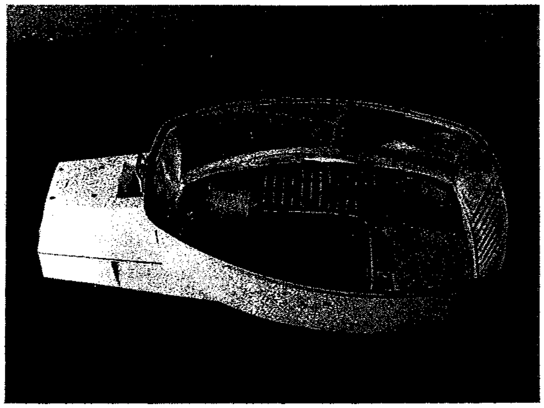
The cutoff type luminaire has been shown to be an effective means of reducing glare in illumination systems; however, since the distribution of light is different from that of conventional roadway luminaires, it is necessary to determine the photometric characteristics of cutoff luminaires to establish optimum mounting height-spacing ratios. It has also become necessary to compare the cutoff designs with Type III semi-cutoff luminaires, one of the more commonly used designs for freeway lighting.

Briefly stated, the scope of this part of Research Project 2-8-64-75 was to investigate the effects of changes in the design of luminaires on the design of roadway lighting systems. Specifically, the objectives were as follows:

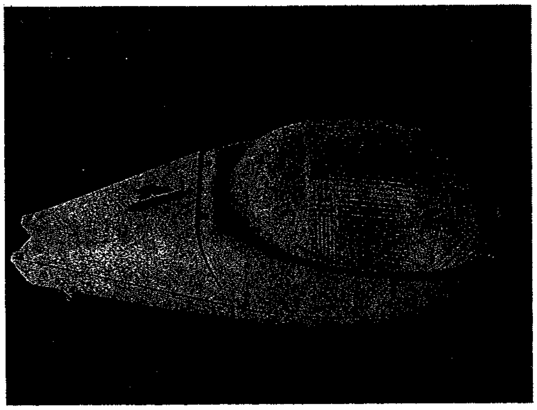
1. To investigate the photometric characteristics of one 400-watt and one 1000-watt cutoff type luminaire (British-made units--see Figure 8).
2. To compare cutoff designs to standard Type III semi-cutoff designs.



Test Facility



Cutoff Luminaire



Type III Luminaire

Figure 8

Measurements of horizontal footcandles were made for the cutoff units. The experimental procedure using synthetic or computer-built systems approximated that of the Type III continuous lighting system studies described in an earlier section of this report. In addition, four systems, representing the two cutoff designs and two Type III designs, were set up at the Highway Illumination Test Facility to provide a comparison between the designs on the basis of brightness and glare, as well as intensity and uniformity of illumination.

The results of the research pertaining to systems of cutoff type luminaires can be summarized as follows:

1. The initial minimum illumination was inversely proportional to longitudinal spacing and roadway width (Figure 9).
2. The rate of reduction of initial minimum illumination, due to an increase in longitudinal spacing and roadway width, was inversely proportional to mounting height.
3. The initial average illumination varied inversely with mounting height and longitudinal spacing; however, as the longitudinal spacing was increased, the rate of the reduction in initial average illumination became smaller as the mounting height was increased (Figure 10).
4. The more desirable uniformity ratios were found at the increased mounting heights.
5. The width of the roadway to be lighted affected the amount and uniformity of illumination for a given cutoff lighting system. For all mounting heights the initial average illumination decreased as the roadway width was increased.

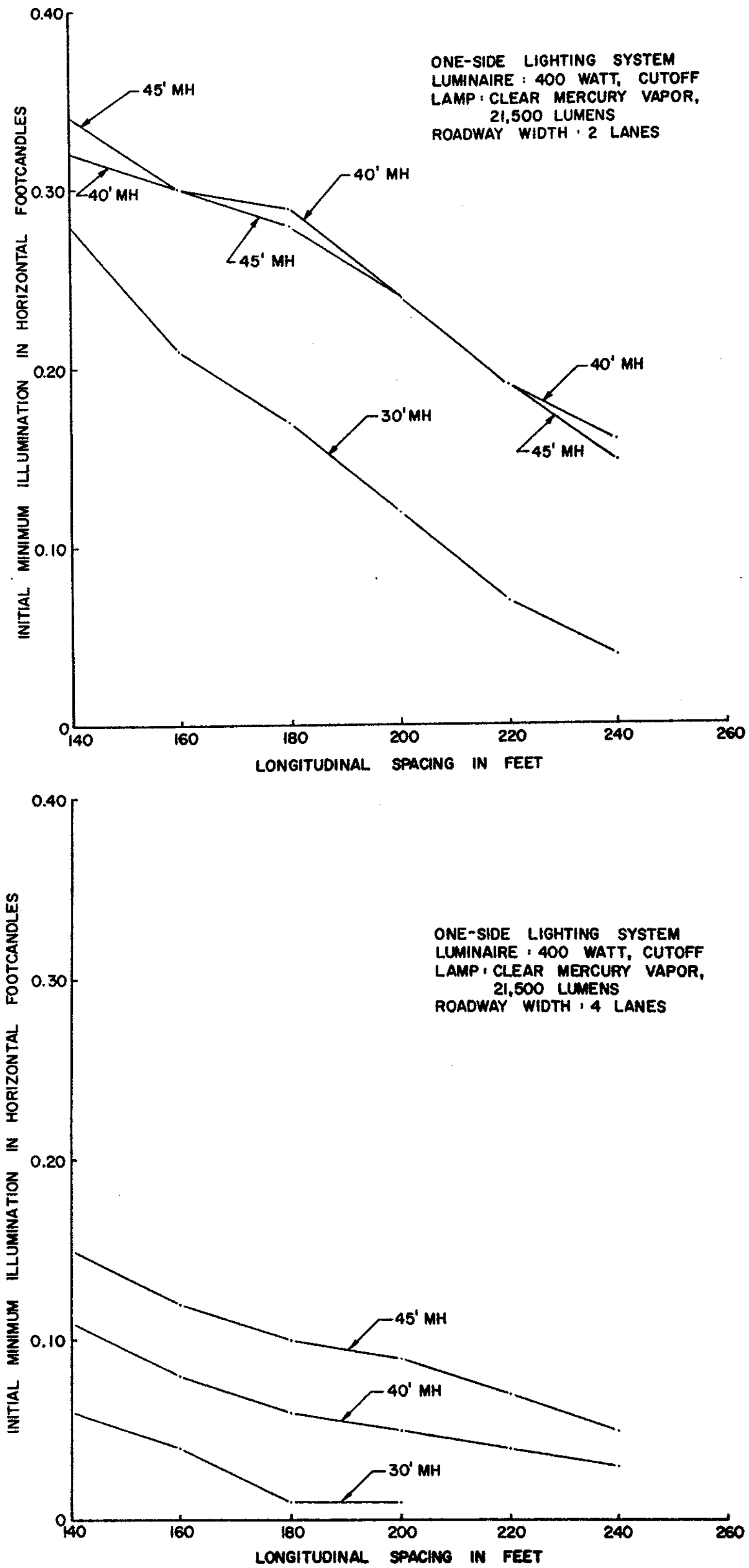


Figure 9. Initial minimum illumination vs. longitudinal spacing for different mounting heights.

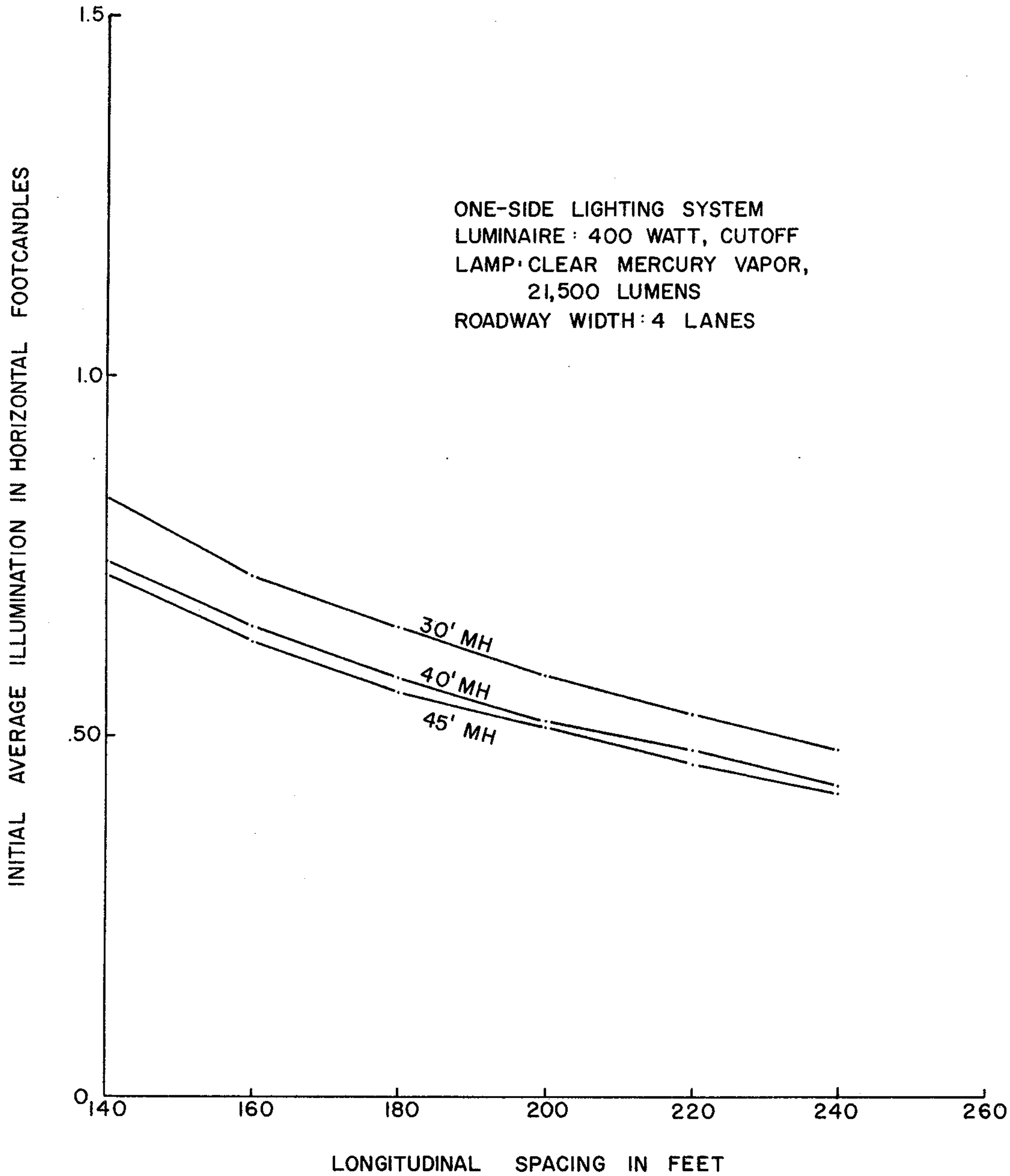


Figure 10. Initial average illumination vs. longitudinal spacing for different mounting heights.

The results of the comparison of cutoff luminaires with Type III luminaires can be summarized as follows:

1. To produce systems with similar photometric characteristics, the Type III luminaires can be spaced at longer longitudinal spacings and higher mounting heights than the cutoff luminaires. For example, the Type III luminaires can be mounted at 40-45 feet and spaced 200-220 feet apart, while the cutoff luminaires are limited to 40-foot mounting heights and 160-foot spacings.
2. There were no appreciable differences in disability veiling brightness (glare) between the cutoff and Type III luminaires when mounted at the higher mounting heights (40 feet for 400-watt luminaires and 50 feet for 1000-watt luminaires).
3. The Type III luminaires were superior in pavement brightness because of their ability to project sufficient light to cover a wider roadway.

The results of this study indicate that for given design criteria Type III luminaires can be used more effectively and economically than the cutoff type luminaires. The increased mounting heights of the 400-watt and 1000-watt Type III luminaires have reduced the glare levels to approximately those for the cutoff units. This is significant, in that no serious problems of glare would be encountered when using Type III luminaires in a system design with the higher mounting heights.

High-Intensity Lamp Designs

Developmental work by the lighting industry on lamps utilizing metallic vapors has resulted in several high-intensity discharge lamp designs. Most interesting and promising of these high-intensity lamps is one that utilizes alkali metallic vapors, primarily sodium, operated at very high temperatures within a compact ceramic arc tube. This 400-watt lamp has an initial efficiency of 105 lumens per watt, with an output of 42,000 lumens. This is twice the output of 21,000 lumens for conventional 400-watt mercury vapor lamps. Due to this major difference, studies were conducted to determine the application of the new lamp design to continuous freeway lighting.

The light distribution of the lamp mounted in a 400-watt Type III luminaire recommended by the manufacturer was measured in terms of horizontal footcandles for mounting heights of 30, 40, 45, 50, and 60 feet. The luminaire was tilted upward to give an adjustment of 3 degrees with respect to the horizontal pipe bracket.

Several one-side lighting systems were computer-generated, using the photometric data from field studies. For each system the average illumination, minimum illumination, and the average-to-minimum illumination ratios on divided roadways of four, six and eight lanes were computed. In building the various systems, the distance the luminaire was offset from the outside edge of the right-hand lane was varied, as well as the longitudinal spacing between the luminaires. The offset distances used were 0, 12.5 and 25 feet.

Briefly, the results of the study of the high-intensity lamp design can be summarized as follows:

1. The average intensities of the high-intensity lamp systems are approximately twice those of the corresponding conventional lamp systems for all the configurations studied.

2. The light patterns of conventional mercury vapor and high-intensity units are similar, but the high-intensity systems have larger ranges with respect to roadway width for all of the system configurations.

3. The acceptable systems, based on photometric parameters, that can be produced with the 400-watt high-intensity lamps approximate those produced with 1000-watt conventional mercury vapor lamps. In other words, the 400-watt high-intensity units mounted at 50 feet and spaced at 300 feet produce approximately the same photometric values as 1000-watt mercury vapor units mounted at 50 feet and spaced at 300 feet.

Although the photometric characteristics of the high-intensity lamp design are promising, several factors were observed during the study that warrant further consideration. First, the equipment has a high initial cost, and the lamp has a short-rated life (6000 hours). There was also some difficulty experienced in the stability of the lamp hardware. In addition, the lamp produced a color approximating that of low voltage incandescent. Should these problems be eliminated or reduced, however, the high-intensity lamp design could play a significant role in the design of future illumination systems.

Sign Visibility

Another important phase in the development of design criteria for economical and functional roadway lighting was a study of the effects of lighting system geometry on roadside sign visibility. A study of this nature was conducted with specific objectives as follows:

1. To evaluate the effects of luminaire mounting heights on roadside sign placement and visibility.
2. To measure sign brightness, background brightness, and disability veiling brightness associated with different luminaire mounting heights, to determine the effective contrast of the signs, and to investigate their effects on sign visibility.
3. To correlate results obtained with previous research findings.

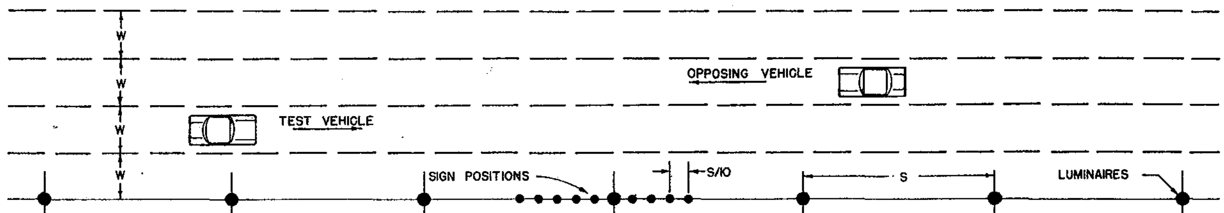
Luminaires were mounted on seven of the towers to represent a one-side lighting system. Figure 11 illustrates the systems studied and the experimental design followed for the visibility tests. To implement these tests, standard destination signs consisting of black letters on a white reflectorized background, were used. Figure 12 illustrates one of these signs mounted on a portable frame that could be moved within the lighting system.

Controlled visibility tests using two observers were conducted, primarily to evaluate the effects of luminaire mounting height on roadside sign placement and visibility. These tests were conducted according to a factorial experimental design that facilitated the evaluation of the significance of and interrelationship among all major factors entering into the problem.

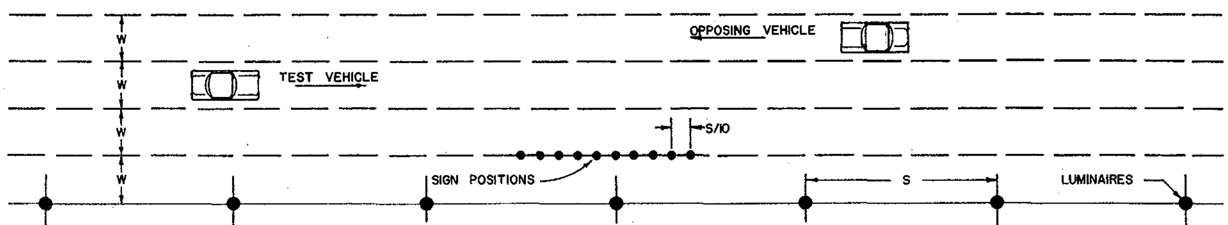
After the visibility tests were completed, brightness and glare measurements were made for each of the legibility positions recorded in the 400-watt visibility tests under bright headlight conditions. The same signs used for the visibility tests were used for this phase.

LEGEND

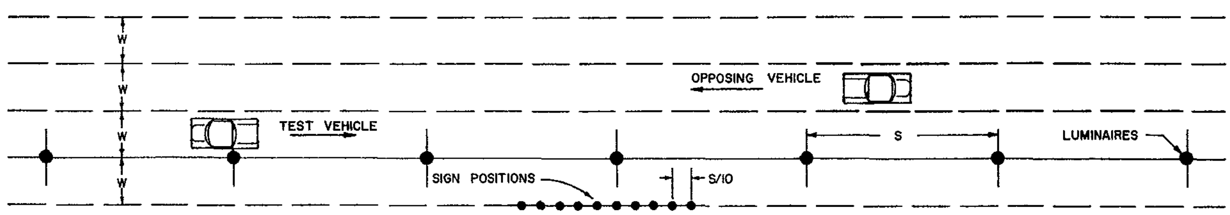
	400-WATT SYSTEMS 30' MH	400-WATT SYSTEMS 40' MH	1000-WATT SYSTEMS 50' MH	1000-WATT SYSTEMS 60' MH
S	200'	200'	300'	300'
S/10	20'	20'	30'	30'
W	12.5'	12.5'	12.5'	12.5'



PLAN VIEW FOR UNDER LIGHT SIGN POSITIONS



PLAN VIEW FOR FRONT LIGHT SIGN POSITIONS



PLAN VIEW FOR BACK LIGHT SIGN POSITIONS

Figure 11

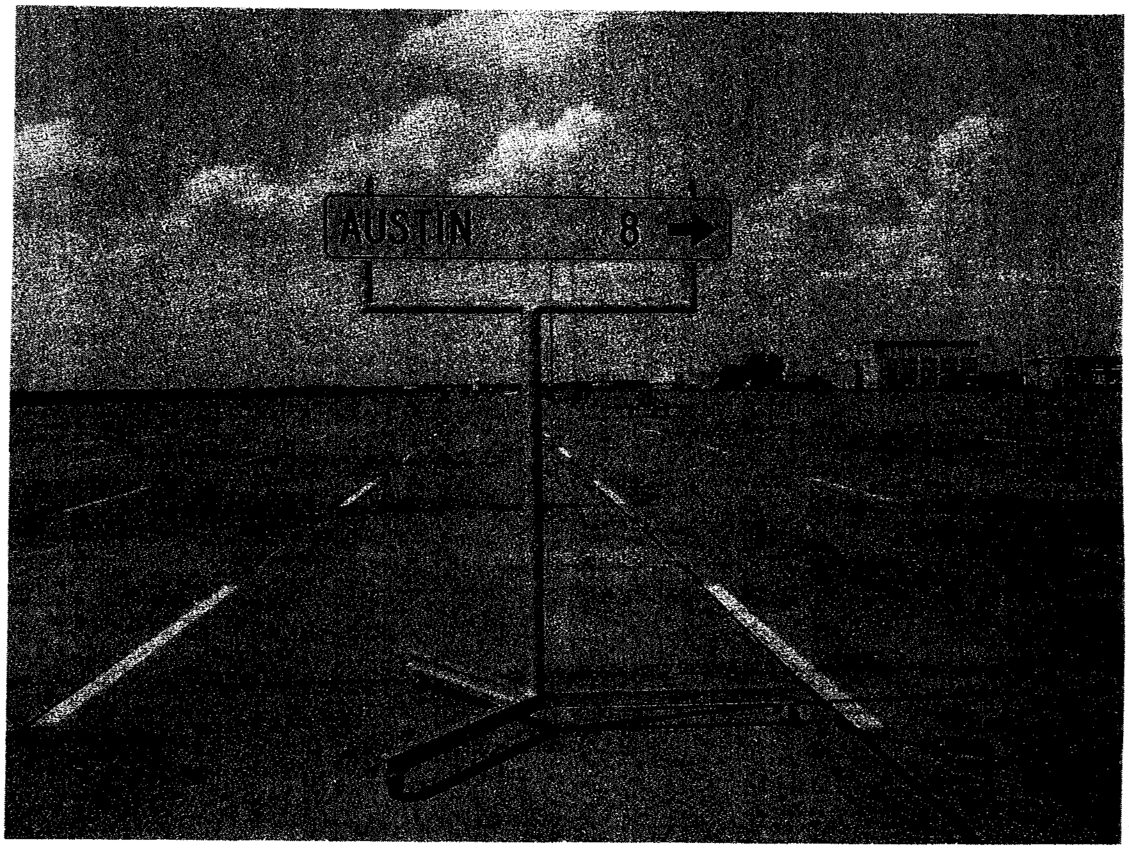
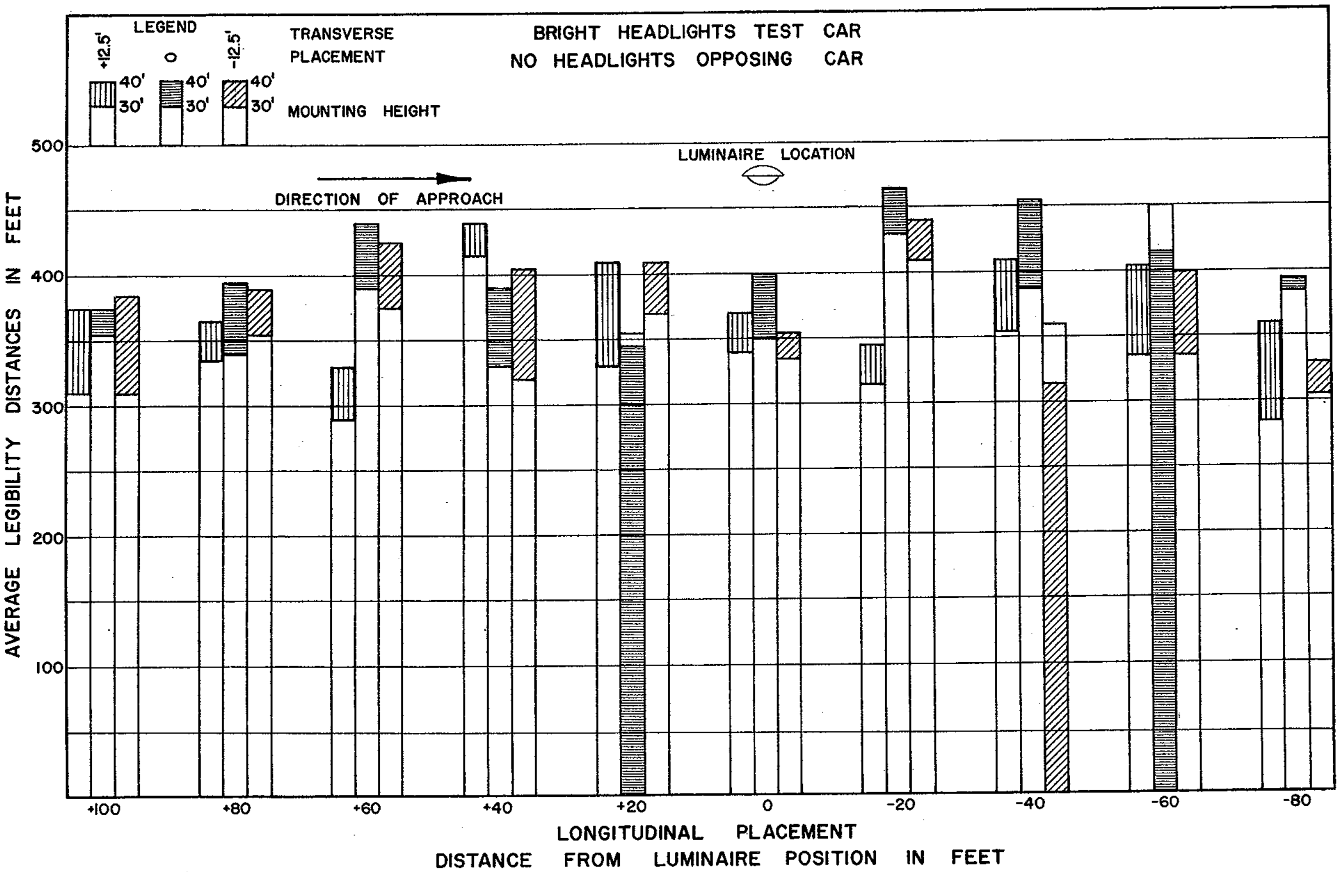


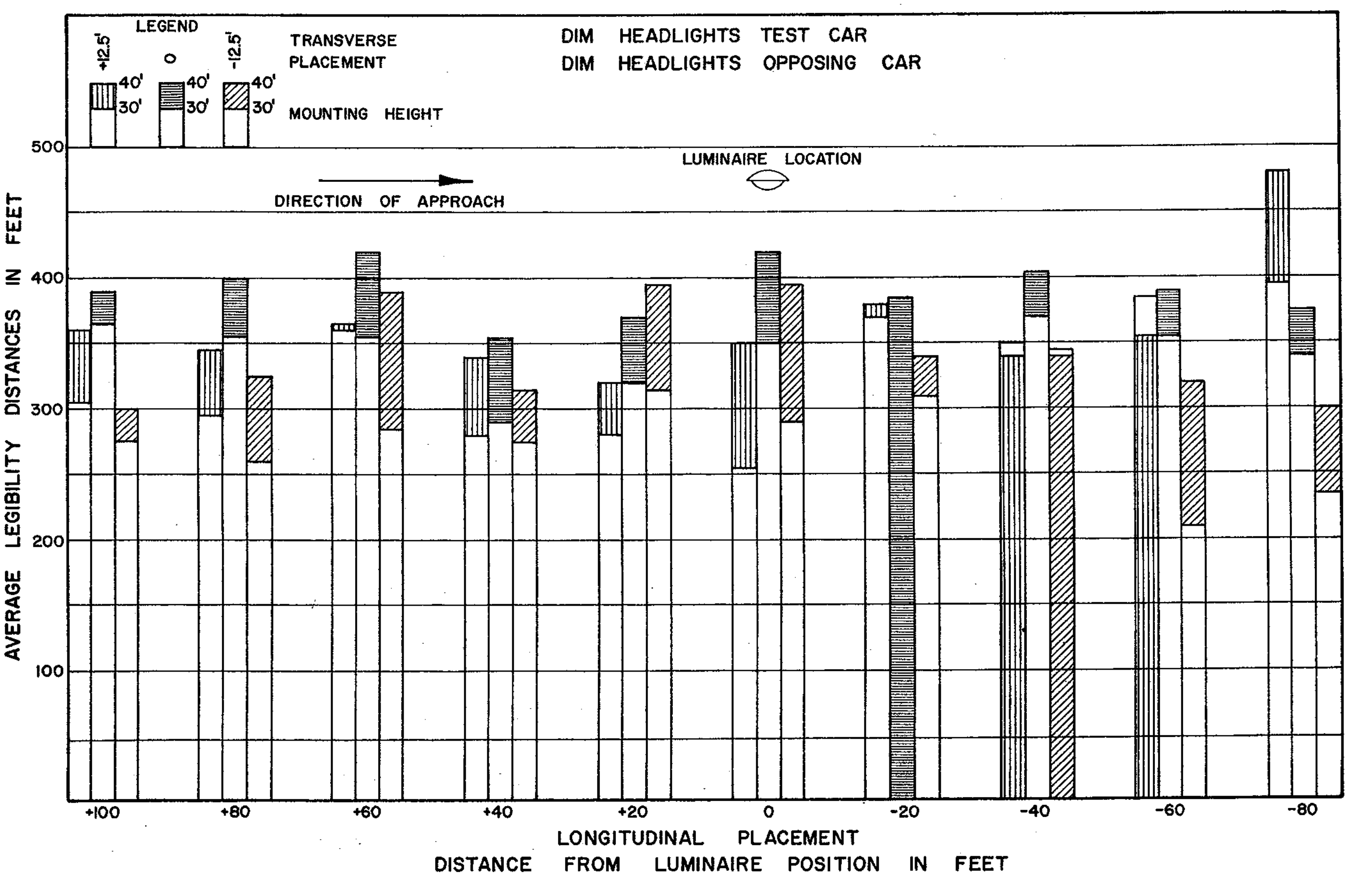
Figure 12. Portable sign frame and test sign.

From studying the selected systems and associated parameters, the following observations were warranted:

1. Significant increases in sign legibility are realized by increasing the mounting height of 400-watt luminaires from 30 to 40 feet (Figure 13). No significant difference is realized in changing the mounting heights of 1000-watt units from 50 to 60 feet.
2. Careful attention should be given to the placement of signs in an illumination system consisting of 400-watt units at 30-foot mounting heights, while no particular problem is encountered with 40-foot mounting heights or with 50- and 60-foot mounting heights of 1000-watt units. For the 30-foot mounting heights the sign should be mounted 20 to 60 feet beyond the light source, so as to receive adequate illumination on the sign face.
3. The higher mounting height of 400-watt units resulted in a system of lower sign brightness and glare levels, but increased legibility distance.
4. A study of effective contrast did not define one system as being optimum with respect to the other. However, the values of effective contrast were nearly constant at .70 for all positions, indicating that a minimum value of effective contrast is necessary for a particular task.

The results of the visibility phase of this study provided good correlation with previous findings of the Texas Transportation Institute. In this study the optimum longitudinal sign positions were located 20





EFFECTS ON LEGIBILITY DISTANCE FOR CONDITIONS SHOWN

Figure 13

to 60 feet beyond the light source from the driver. In previous studies the optimum was found to be from 20 to 75 feet.[1] This applies only to 400-watt units mounted at 30-foot heights.

Controlled Visibility Tests

To further determine the effectiveness of lighting systems with various geometric configurations, controlled visibility tests were conducted. The tests involved identifying the orientation of a bar on a 24-inch diameter circular disk with contrasting shades of gray.

Seven lighting system configurations were used in the study. They are as follows:

1. 200-foot spacing, 30-foot mounting height, 400-watt
2. 200-foot spacing, 40-foot mounting height, 400-watt
3. 220-foot spacing, 30-foot mounting height, 400-watt
4. 220-foot spacing, 40-foot mounting height, 400-watt
5. 240-foot spacing, 40-foot mounting height, 400-watt
6. 240-foot spacing, 50-foot mounting height, 400-watt
7. 260-foot spacing, 50-foot mounting height, 400-watt

Data were collected by two observers for each of the seven system configurations. Fifteen target test positions were used, five positions in each of three lanes. Four target orientations were employed, horizontal, vertical and at 45-degree angles (left and right).

Analysis of variance techniques were used to determine the significance of visibility difference for the various systems. Hartley's sequential range test revealed that system number 6 was significantly superior to all other systems. It also revealed that system number 1 was significantly inferior to all other systems. There were no significant differences between the other five systems.

General Design Guidelines

Most of the results obtained in this phase of the research study have been used by the Texas Highway Department and others to develop guidelines for the design of continuous illumination systems. Based on the research and experience with the new lighting systems thereby resulting, the following guidelines are offered for design of continuous lighting systems for freeway type facilities.

Intensities

Adequate lighting will be achieved if the average intensity of lighting on the roadway meets or exceeds:

Rural	Urban
.6 hor ft-cd.	1.0 hor ft-cd.

Uniformity

Average to minimum ratios of uniformity should not exceed:

Rural	Urban
3 to 1	3 to 1

Maximum to minimum intensity on any given lane should not exceed:

Rural	Urban
5 to 1	5 to 1

Maximum to minimum ratios between adjacent lanes should not exceed:

Rural	Urban
3 to 1	3 to 1

Spacing-Mounting Height Ratios. To achieve acceptable uniformity with freedom from excessive glare, minimum heights of 40 feet and 50 feet should be used for the 400-watt and 1000-watt Type III medium distribution, semi-cutoff luminaires, respectively. Spacing to mounting height ratios should not exceed the following for 1000-watt luminaires:

Light Pavement		Dark Pavement	
Rural	Urban	Rural	Urban
6 to 1	6 to 1	5 to 1	5 to 1

For 400-watt luminaires the ratios should not exceed:

Light Pavement		Dark Pavement	
Rural	Urban	Rural	Urban
5 to 1	5 to 1	4 to 1	4 to 1

Lateral Placement. From the safety standpoint, placement of supports should be as far from the travel way as possible, except when incorporated with barrier protection. For lighting uniformity, a minimum lateral placement of 12 to 15 feet will insure better uniformity on the roadway by removing the prevalent "hot-spot" normally located immediately under and out from the luminaire.

INTERCHANGE LIGHTING

INTERCHANGE LIGHTING

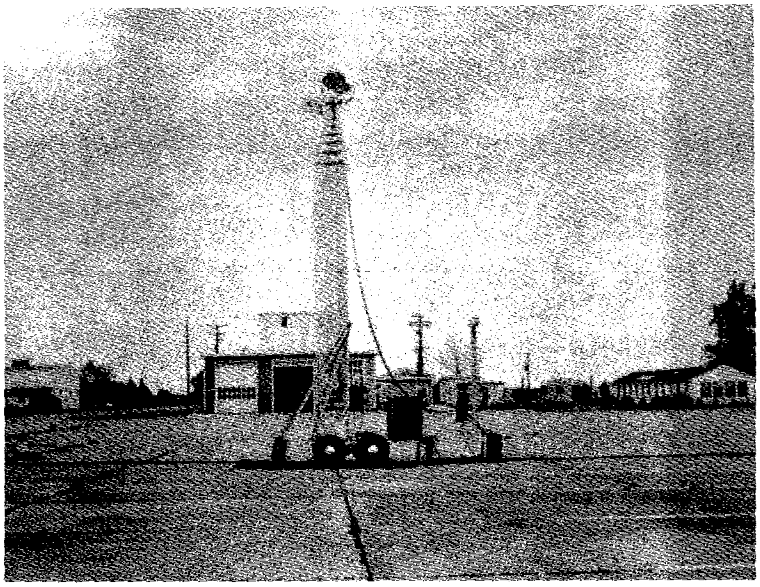
The complexity of modern interchanges and the presence of roadways of greatly varying character entering at different levels require more than conventional lighting systems can provide. Because of this problem, a very significant portion of the work in Research Study 2-8-64-75 was devoted to high-mast lighting of interchange areas.

Engineers of the Texas Highway Department expressed considerable interest in experimental lighting projects in Europe which utilized floodlights mounted on high masts to illuminate entire interchange areas. This interest stimulated similar concepts investigated in this research.

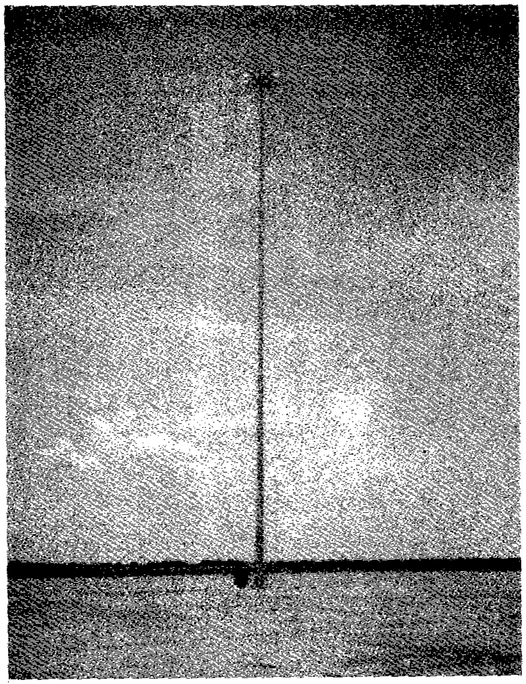
As one of the initial investigations in this study, the research agency, with the cooperation of the City of Austin, Texas, and the Texas Highway Department, conducted photometric studies on one of the 150-foot "moonlight" towers in Austin. These studies were conducted to determine the possible application of similar lighting towers to highway use. All of those participating in the research were very impressed and unanimous in their observation that similar concepts could have application.

Facilities to further investigate the high-mast concept were developed at the Texas A&M Research Annex (Figure 14). These facilities have been used in the development of experimental systems for application to highway interchanges.

The first system developed consisted of ten 1000-watt mercury vapor floodlights mounted at 100 feet and aimed initially at 45 degrees



120-FOOT TELESCOPING TOWER



150-FOOT FIXED STEEL POLE

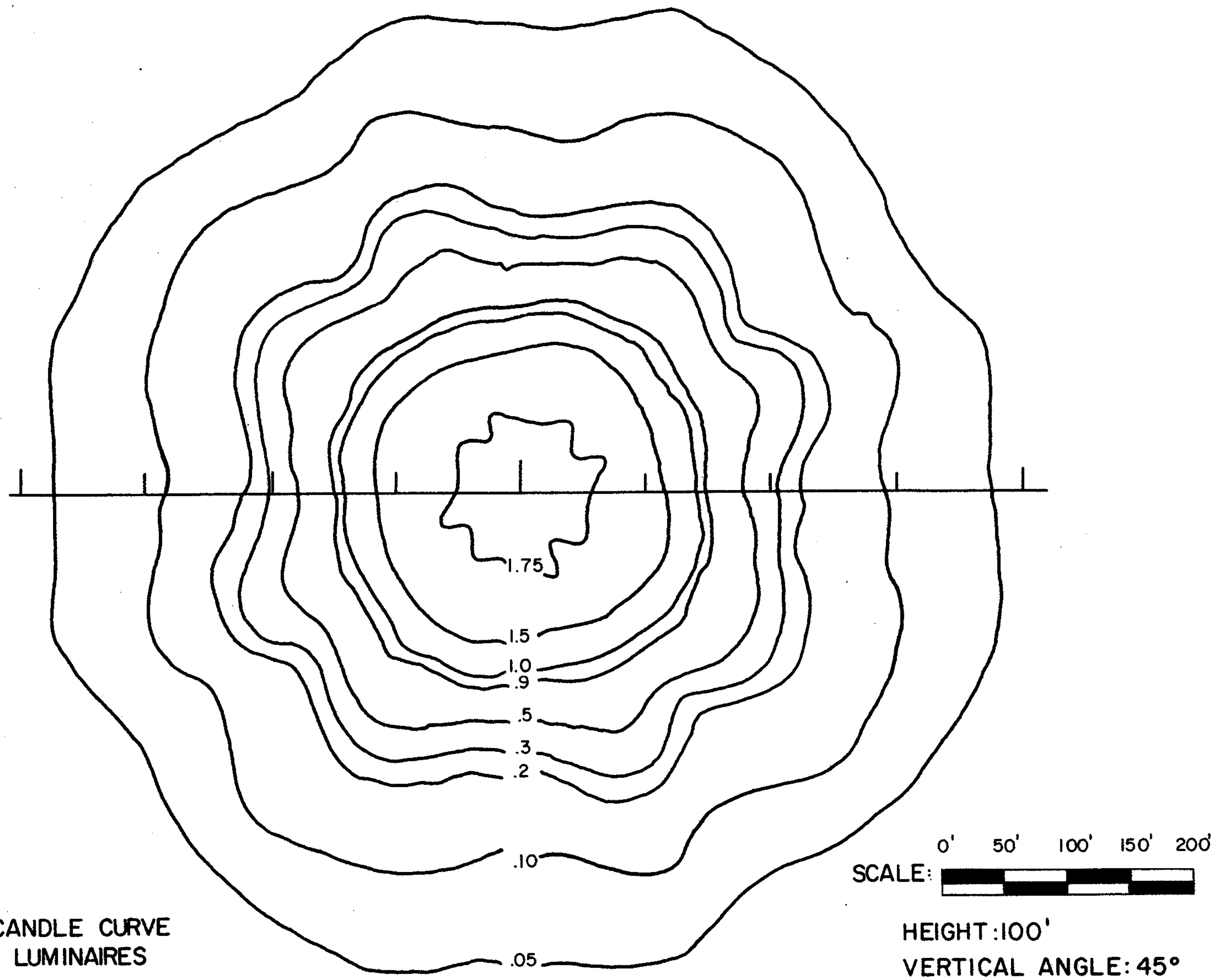
Figure 14 . High-level lighting test facilities.

with the down vertical axis of the support (see Figure 15 for the photometrics of this system). This system underwent numerous tests at the Research Annex and was field tested for subjective evaluation in a large interchange area in Fort Worth, Texas (Figures 16 and 17). Approximately 40 professional engineers attended the Fort Worth test, with all agreeing that the system should receive serious consideration for immediate application.

An additional field test was conducted at a large, diamond interchange in Huntsville, Texas (Figure 18), utilizing two 100-foot towers. A diagnostic team, consisting of representatives from the research agency, Texas Highway Department, and the Bureau of Public Roads, was assembled to evaluate the test installation. There was full agreement that the lighting was far superior to the conventional safety lighting previously installed at the interchange and compared with the two towers. There were reservations, however, that the two towers were spaced too far apart (approximately 1400 feet) and possibly would be improved if spaced approximately 1000 feet apart.

Based on the studies at the Research Annex and the two field locations, the sponsors decided that full-scale installations should be made in order to evaluate a complete system of the towers. Two such installations were made, one in Texarkana, Texas-Arkansas, and one in San Antonio, Texas.

Texarkana. The installation in Texarkana is located at a tight cloverleaf interchange at the intersection of IH 30 with US 59-71 (Figure 19). Both highways are four-lane divided. The design consisted of one 150-foot tower, equipped with ten 1000-watt floodlights,



ISO FOOTCANDLE CURVE
1000-WATT LUMINAIRES

FIGURE 15

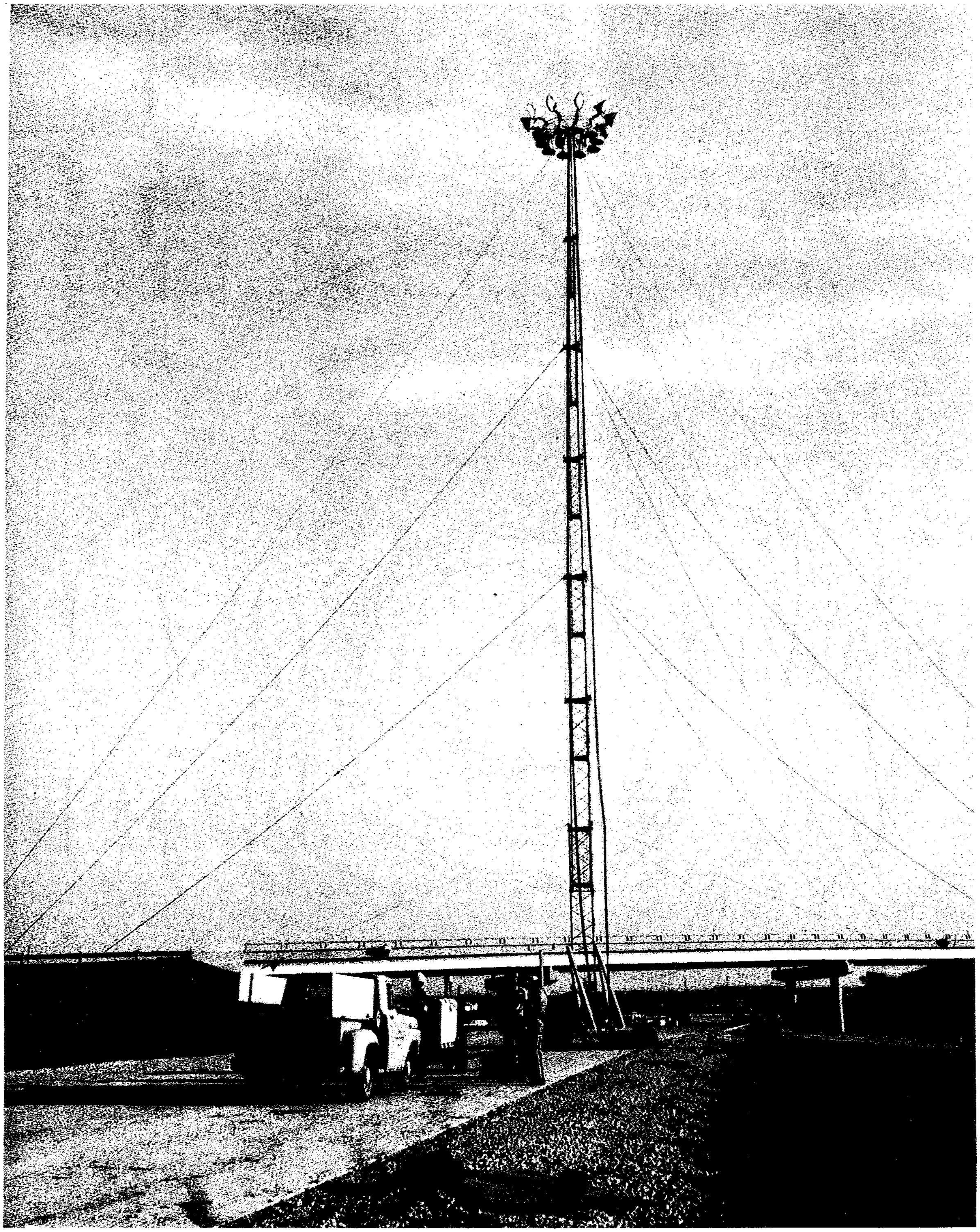


Figure 16. High-level test installation in Fort Worth.

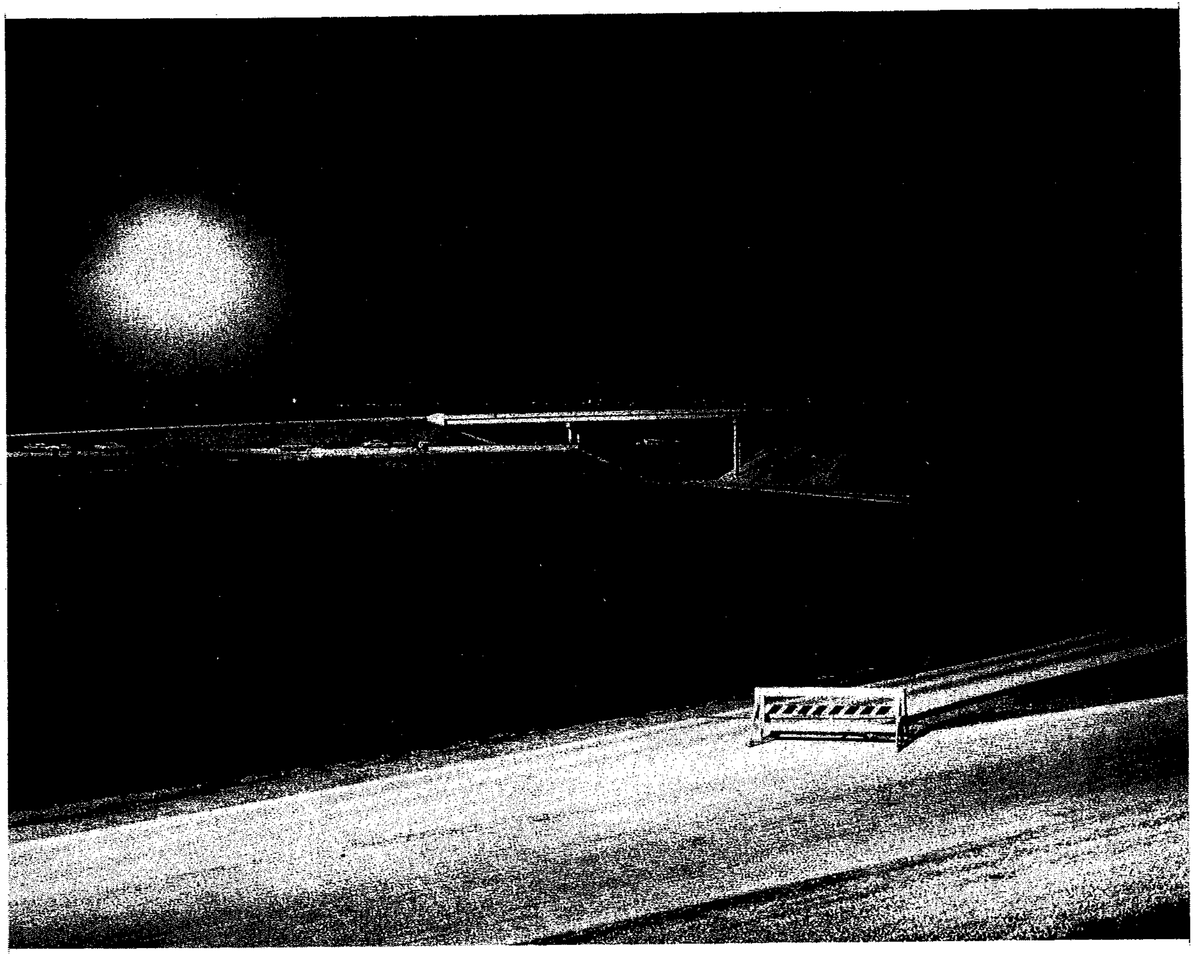


Figure 17. High-level test installation in Fort Worth.

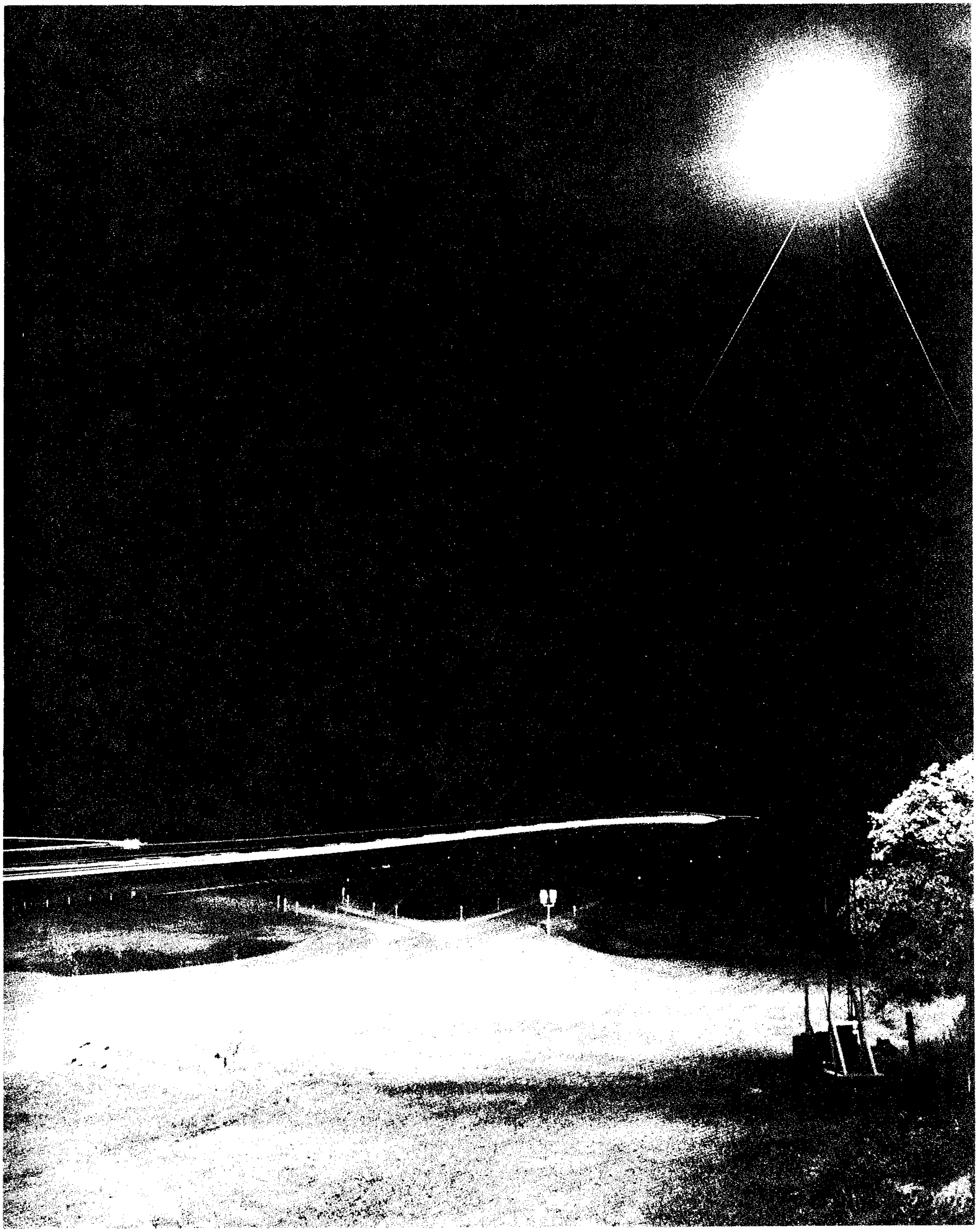


Figure 18. Night view of Huntsville installation.

TEXARKANA HIGH-MAST LOCATION

FIGURE 19

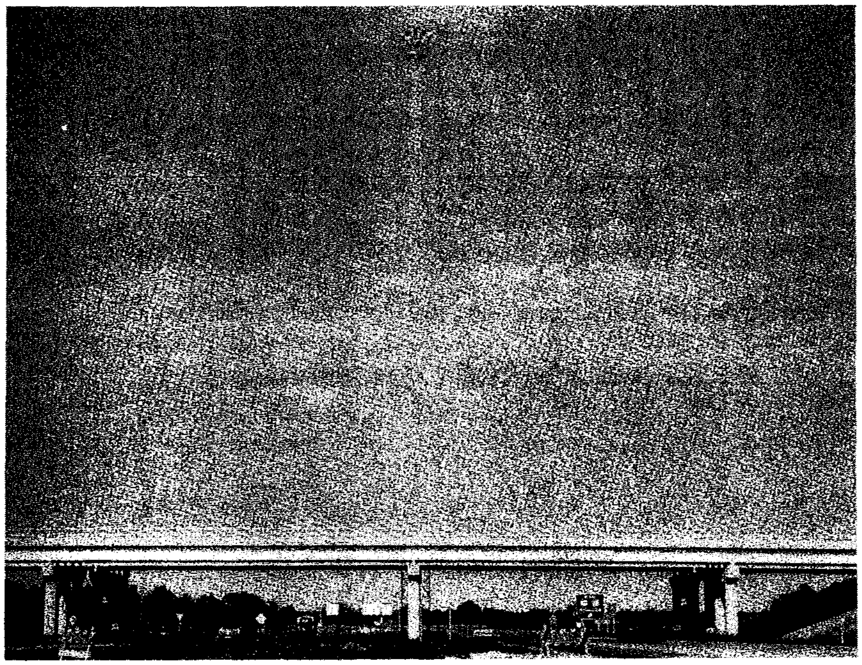
located in the geometric center of the interchange and one 100-foot tower, equipped with six 1000-watt floodlights, located on each of the approach legs of the interchange (Figure 20). The towers are spaced approximately 1000 feet apart. It was anticipated that this design would yield the minimum photometrics necessary for safe and efficient operation in the interchange.

At the completion of the Texarkana installation, the research staff planned and conducted studies at the location. These studies included diagnostic evaluation by a professional team of engineers and operational studies, including speed measurements and galvanic skin response for before and after test conditions. The purpose of the studies was to investigate the effectiveness of the installation in relation to night visibility and driver performance.

From the answers to the diagnostic questionnaires, it was found that the majority of the professional team considered the installation adequate for safe and efficient operation. It was indicated, however, that the towers were spaced too far apart and, in a few cases, dark areas were the result.

Galvanic skin response studies under the before and after study conditions were somewhat inconclusive, although with the lighting system in operation, responses were much less frequent and smaller in magnitude than those experienced during the "lights off" condition. This may suggest that driver tension was less with the lighting system in operation.

The speed measurement studies indicated generally higher operating speeds when the illumination system was in operation.



TEXARKANA INSTALLATION

FIGURE 20

The findings of the research at the Texarkana site demonstrated the technical and economic* feasibility of high-mast lighting. Major objections to the installation were the long spacings between towers creating dark spots, noticeable glare from towers directly in line of sight, and one or two "hot spots" on the roadway adjacent to one of the towers on an approach leg to the interchange.

San Antonio. The installation in San Antonio is at a large interchanging area on IH 410, consisting of one large cloverleaf and one directional interchange (Figure 21). The design consisted of twenty 100-foot towers, in conjunction with conventional lighting mounted at 50 feet (Figure 22). Spacings between towers were on the order of 1000 feet.

At the completion of this installation, a diagnostic study was conducted. The team consisted of representatives from the Texas Highway Department, the Bureau of Public Roads, the lighting industry, and the research agency.

The study was conducted according to two independent approaches, under two conditions. The first condition was with the recently-installed lighting system turned off. This condition prevailed the first night of the study and the major portion of the 33-mile study route was without illumination. On the second night, however, the new system was turned on, and the various types of lighting, including old and new, were evaluated.

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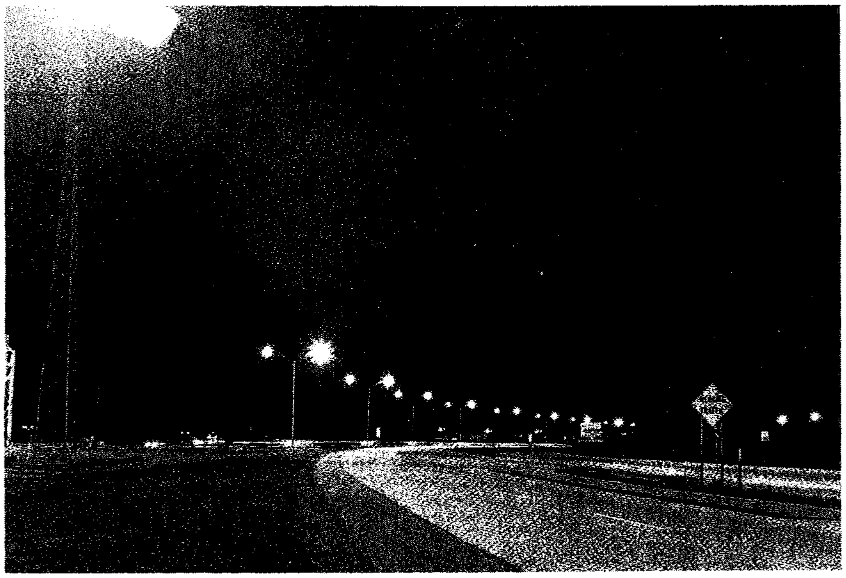
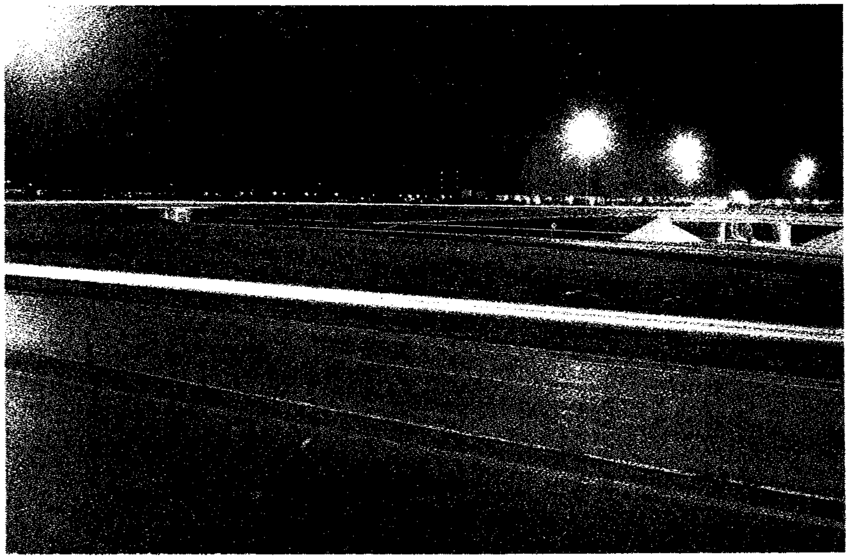
*The high-mast installation in Texarkana cost approximately $30,000. Continuous lighting using conventional methods was estimated to cost from $40,000 to $58,000, depending on use of 400- or 1000-watt luminaires.

SAN ANTONIO HIGH-MAST LOCATION

FIGURE 21





SAN ANTONIO INSTALLATION

FIGURE 22

The two approaches employed involved a specific evaluation of illumination, as related to the geometrics and design of the study site and a general evaluation of roadway illumination system characteristics.

The professional team, after completing the two nights of study, responded to questionnaires provided by the research agency. Part A of the questionnaire pertained to an evaluation of the benefits of continuous lighting. The results can be summarized as follows:

> "Dark freeway conditions result in a very insecure and lost feeling on the part of a motorist. Decision points cannot be identified in adequate time to make required maneuvers safely and efficiently. There is a feeling of tension that leads to reduced speed and very often missed turns and maneuvers. In the lighted section (conventional lighting) there was a more relaxed and comfortable feeling. Decision points were easier to identify, and higher speeds were possible. It was also possible to determine roadway characteristics which produced a comfortable environment."

Part B of the questionnaire was devoted to a comparison of lighting techniques and to recommendations of ways of improving these techniques. Briefly, the results from Part B can be summarized as follows:

> "High-mast lighting is definitely superior to other types of lighting for interchange areas. For the lighting of continuous roadway sections, it compares very favorably with the conventional techniques. Of the conventional systems studied within the study route, the higher mounted (50 feet), median lighting was definitely superior."

It was suggested that high-mast lighting could be improved by more careful location of the towers, to insure that they are never in the direct line of sight, and through use of lower-aiming angles (45-degree maximum) to reduce glare. It was indicated that the side-mounted, 30-foot mounting height continuous system could be improved only through higher mounting heights. Suggested improvements on the median lighting included closer spacings (250 feet) and extra units at ramp locations.

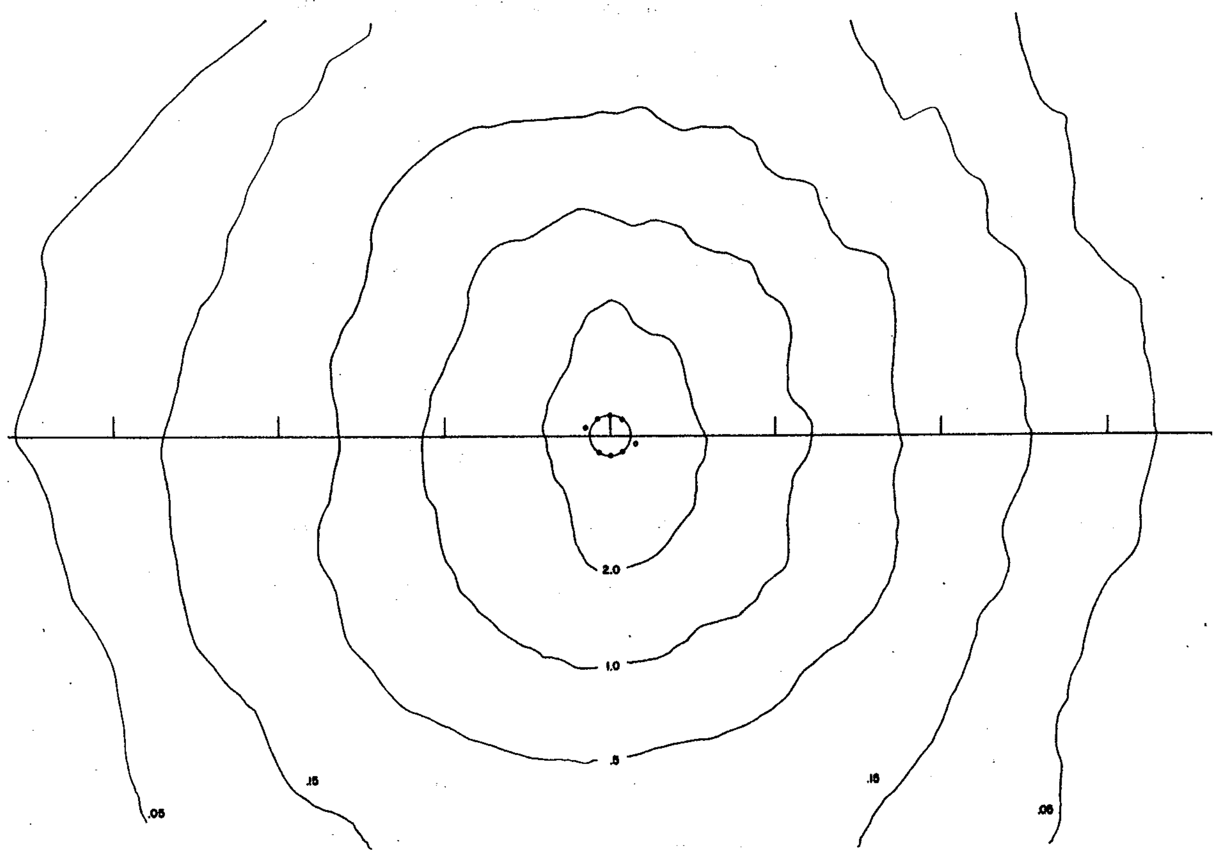
Additional Studies. Additional studies were conducted at the Research Annex, in an effort to determine optimum heights for high-mast lighting and general guidelines for design. Included in these additional studies was the investigation of IES Type V luminaires for high-mast lighting.

Photometric characteristics for the Type V luminaire have been determined, and a typical system would yield the photometrics shown in Figure 23. The number of units per tower will dictate the area of coverage and intensity levels. At the present time, this technique of high-mast lighting compares favorably with floodlighting and should be considered for application. The technique is being further investigated in Research Study 2-8-69-137.

General Observations. From the research on high-mast interchange lighting and experience with the field installations, the following general observations can be made:

1. The high-mast concept is both technically and economically feasible.
2. The concept is superior to conventional techniques in providing safe nighttime driving environments in interchanges.
3. The minor problems encountered in these studies of high-mast lighting are being corrected in further study and application of the concept.

General Design Guidelines. It is not possible to give complete guidelines in the use of high-mast lighting, since the concept is new and experience brief. The research staff does feel, however, that the



ISO FOOTCANDLE CURVE
EIGHT 1000-WATT MERCURY VAPOR,
8-INCH LIGHT CENTER HEIGHT : 150 FEET
SCALE : 0 50 100 150 200

FIGURE 23

following guidelines, based on research and experience, can be used effectively with sound engineering judgment in the design of high-mast lighting.

Intensity

The field installations have indicated that average intensities on roadways within the interchange should equal or exceed:

Rural	Urban
.30 hor. ft-cd.	.50 hor. ft-cd.

For areas adjacent to roadways the intensities should equal or exceed:

Rural	Urban
.05 hor. ft-cd.	.10 hor. ft-cd.

In addition, horizontal illumination, or that illumination striking vertical surfaces, should be maintained as high as possible without creating undue glare.

Uniformity

Uniformity of illumination (average to minimum) on the roadway should equal or exceed

Rural	Urban
2 to 1	2 to 1

Maximum to minimum ratios on the roadway should not exceed:

Rural	Urban
4 to 1	4 to 1

For areas adjacent to the roadway sound engineering judgment should be the guideline.

Placement of Supports. High-mast towers or poles should be placed as far from the roadway as is possible, to reduce maximum intensities on the roadway and to reduce potential hazard. In addition, very careful consideration should be given to placement, to assure that lights are never in the direct line of sight from the roadway and that aiming angles (for floodlights) do not exceed approximately 45 degrees with the down vertical axis of the support.

By following these guidelines, acceptable spacings between towers can be on the order of 600-800 feet, depending upon placement.

Mounting Height. Although very acceptable results have been obtained at heights of 100 feet, it is apparent from recent installations, notably Dallas, that mounting heights of 150 feet are desirable. This additional height not only covers larger areas, but allows greater flexibility in placement of supports and aiming of the floodlights.

At heights of 150 feet it has been found that ten 1000-watt floodlights aimed at approximately 45 degrees produce excellent results. Spacings can be on the order of 700-800 feet, and the aiming angle can be controlled to eliminate excessive glare.

SAFETY CONSIDERATIONS

IMPACT BEHAVIOR OF LUMINAIRE SUPPORTS

The severity of collisions with luminaire supports on Texas highways prompted the Texas Highway Department to include, within Research Study 2-8-64-75, an investigation dealing with the impact behavior of such supports. The object of the study was to determine the impact characteristics of various pole and base mounting designs now in use on Texas highways.

The "state-of-the-art" study consisted of conducting full-scale crash tests of various luminaire support designs. All of the crash tests were conducted as head-on collisions with the lighting poles. Standard sedans of 1954 to 1959 vintage were used, except for one test which involved a 2100-pound compact sedan.

These tests were conducted using the crash test facilities previously developed for sign support research. The procedure for accomplishing the collisions is referred to as the "reverse tow" procedure. This procedure is well-documented in earlier reports.

High-speed motion picture photography was used as the principal means of obtaining data on the crash tests. Several cameras, including one capable of filming speeds of 1000 pictures per second, were used. Electronic instrumentation was used to a limited extent.

A description of the various designs tested is presented in Table 2. The designs are also illustrated in Figure 24.

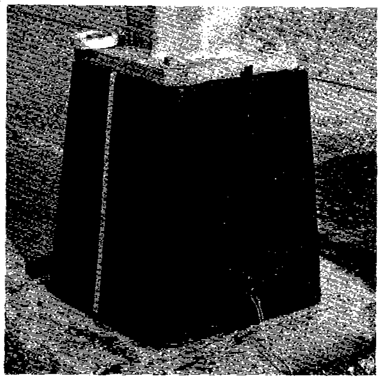
Speed data for the various tests are summarized in Table 3. This summary gives speeds before and after impact, and the resulting reduction in speeds.

TABLE 2

POLE AND BASE COMBINATIONS

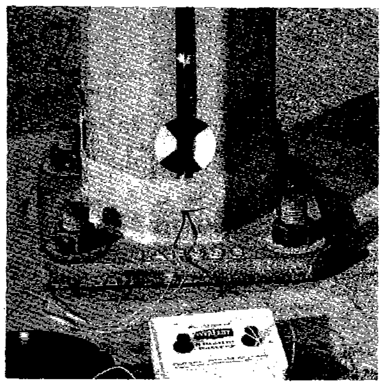
TESTED IN THE "STATE OF THE ART" STUDY

Combination	Number of Tests	Impact Speed, MPH
Steel Pole - Aluminum Transformer Base	3	22.2 44.8 45.7 (Compact Sedan)
Aluminum Pole - Aluminum Transformer Base	2	21.3 43.2
Steel Pole - Steel Transformer Base - Aluminum Insert	2	32.2 53.2
Flange-Mounted Steel Pole	1	40.5
Flange-Mounted Aluminum Pole	1	44.0
Steel Pole - Steel Transformer Base	1	39.4

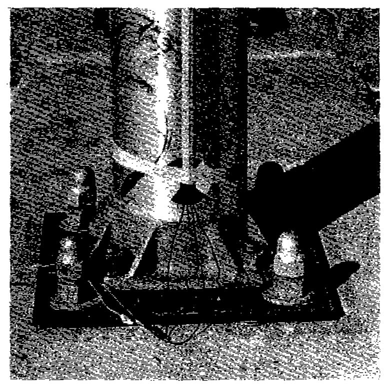


STEEL POLE-STEEL
TRANSFORMER BASE

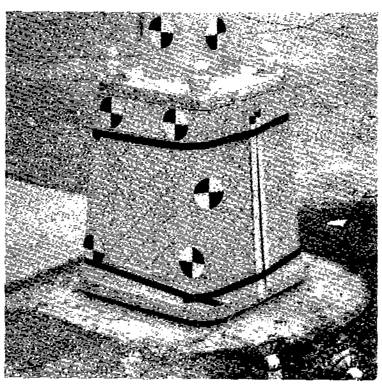
STEEL POLE-STEEL TRANSFORMER
BASE WITH ALUMINUM INSERT



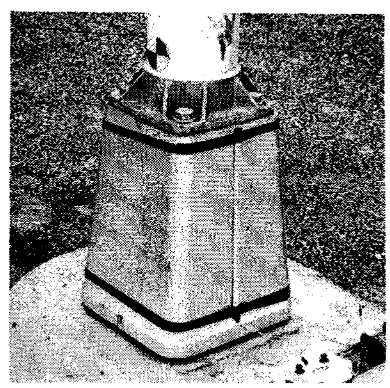
FLANGE MOUNTED STEEL POLE



FLANGE MOUNTED ALUMINUM POLE



STEEL POLE-ALUMINUM
TRANSFORMER BASE



ALUMINUM POLE-ALUMINUM
TRANSFORMER BASE

FIGURE 24
VARIOUS POLE AND BASE COMBINATIONS TESTED

TABLE 3

CHANGE IN SPEED AND DEFORMATION

OF VEHICLE IN COLLISION WITH LIGHTING

POLE AND BASE COMBINATIONS

Combination	Vehicle Make	Vehicle Weight, Lb.	Speed Before Impact, MPH	Speed After Impact, MPH	Change in Speed, MPH	Deformation of Vehicle, In.
Steel Pole - Aluminum Transformer Base	1959 Ford	3460	22.2	17.8	4.4	12.7
	1959 Ford	3700	44.8	41.5	3.3	15.5
	1960 Simca	2140	45.7	38.0	7.7	12.3
Aluminum Pole - Aluminum Transformer Base	1959 Ford	3680	21.3	17.0	4.3	10.9
	1957 Ford	3600	43.2	38.0	5.2	10.2
Steel Pole - Steel Transformer Base Aluminum Insert	1955 Ford	3460	32.2	27.3	4.9	14.4
	1955 Ford	3580	53.2	47.0	6.2	15.8
Flange-Mounted Steel Pole	1958 Ford	3600	40.5	29.2	11.3	27.4
Flange-Mounted Aluminum Pole	1957 Ford	3500	44.0	37.2	6.8	23.1
Steel Pole - Steel Transformer Base	1958 Ford	3700	39.4	0.0	39.4	30.0

In order to obtain a relative comparison of the severity of impact in each of the collisions, a comparison was made of the momentum of the vehicles before and after collision with the pole. The momentum lost during the impact was calculated for each test, and the results are summarized in Table 4, which shows the relative impact severity of the several designs tested. The change in momentum is one of the indicators often used to compare impact severity.

A comparison of the various designs tested, made on the basis of changes in momentum, is illustrated in Figure 25. This comparison shows that there are only small differences in the changes in momentum, with the exception of the flange-mounted steel pole and the steel pole with a steel transformer base. On the basis of this comparison, it would appear that the frangible base, such as the cast aluminum transformer base or the cast aluminum insert, produced satisfactory impact behavior of lighting poles.

For another means of comparison, the deformation or penetration of the vehicle due to the impact was plotted as shown in Figure 26. This comparison shows essentially the same results as indicated by the comparison of the changes in momentum, except for the flange-mounted aluminum pole. In comparison, the aluminum pole does not show a great advantage over the steel pole. From experience, such severity may not cause a fatality, but would likely result in personal injury to the vehicle occupants.

The conclusions that can be drawn from the "state-of-the-art" study can be summarized as follows:

1. The cast aluminum transformer bases have proven to be

TABLE 4

CHANGE IN MOMENTUM OF VEHICLE

IN COLLISION WITH LIGHTING POLE AND

BASE COMBINATIONS

Combination	Impact Speed, MPH	Momentum Before Collision (Lb-Sec)	Momentum After Collision (Lb-Sec)	Change In Momentum (Lb-Sec)
Steel Pole Aluminum Transformer Base	22.2	3475	2803	672
	44.8	7550	7000	550
	45.7 (Compact)	4450	3700	750
Aluminum Pole Aluminum Transformer Base	21.3	3555	2845	710
	43.2	7070	6120	950
Steel Pole - Steel Transformer Base - Aluminum Insert	32.2	5070	4300	700
	53.2	8660	7660	1000
Flange-Mounted Steel Pole	40.5	6630	4790	1840
Flange-Mounted Aluminum Pole	44.0	7030	5930	1100
Steel Pole - Steel Transformer Base	39.4	6620	0	6620

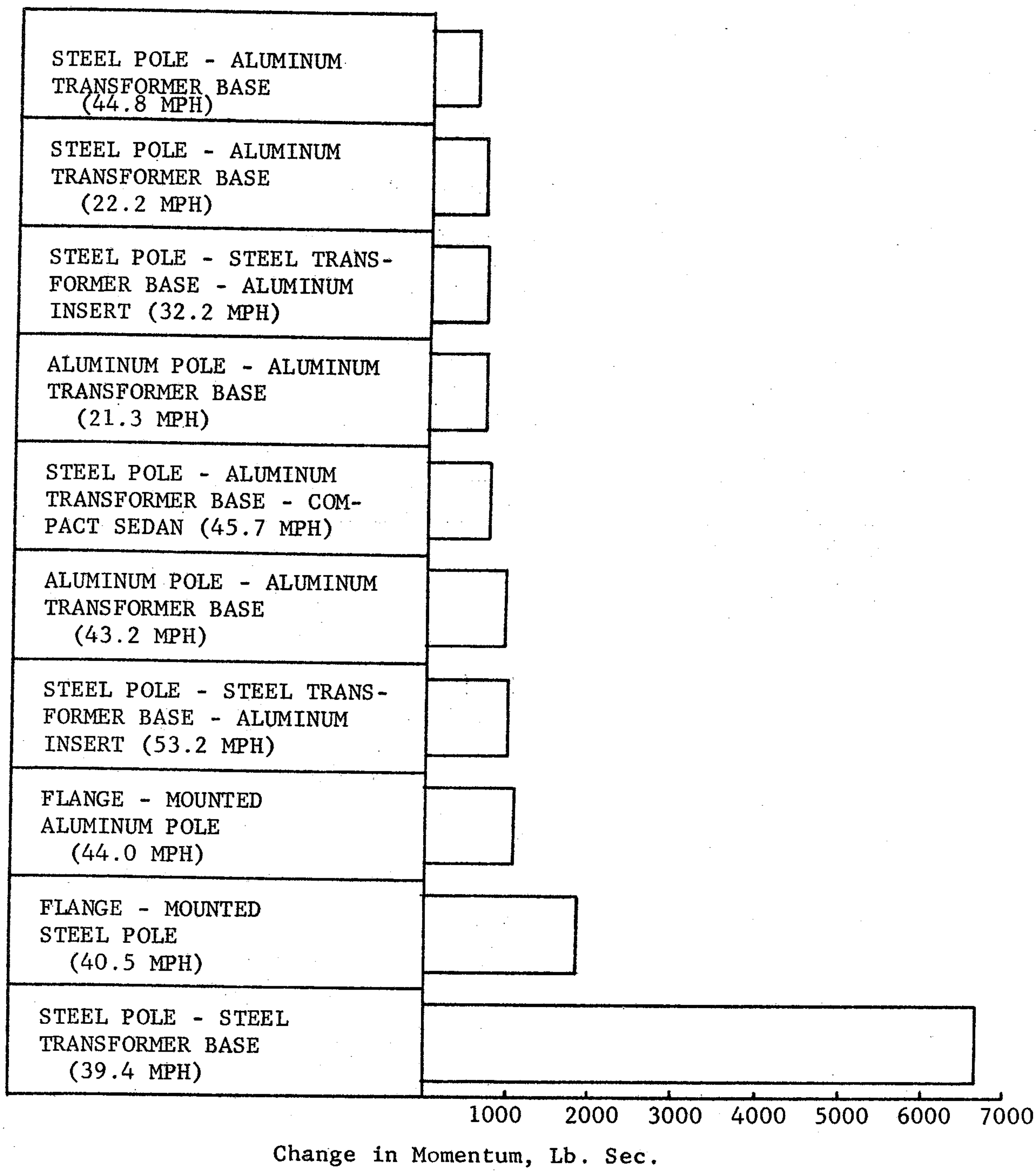


FIGURE 25

COMPARISON OF POLE AND BASE COMBINATIONS ON THE BASIS OF CHANGE IN MOMENTUM

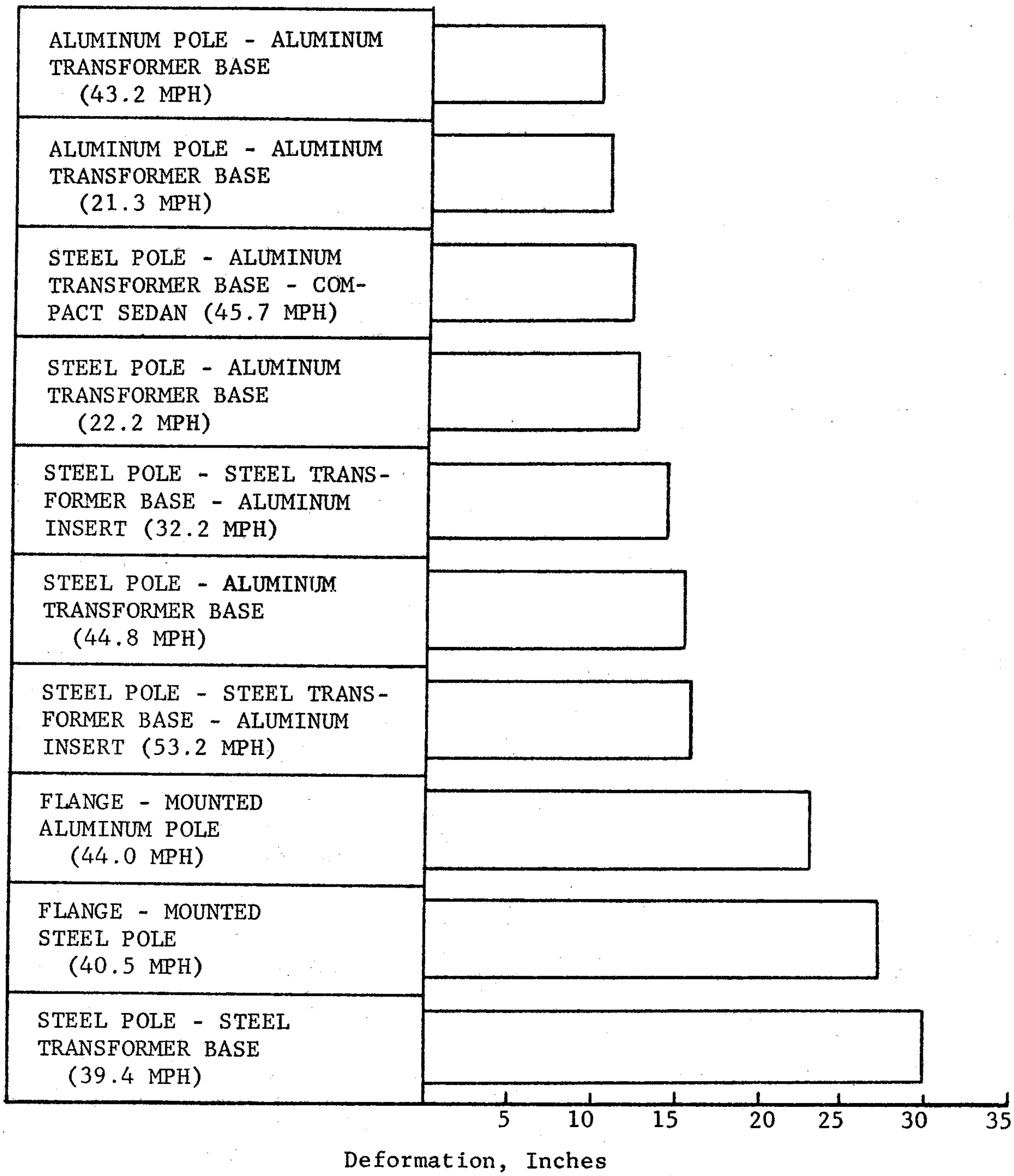


FIGURE 26

COMPARISON OF POLE AND BASE COMBINATIONS ON THE BASIS

OF DEFORMATION OF FRONTAL AREA OF VEHICLE satisfactory failure mechanisms in reducing the impact severity of vehicular collisions with lighting poles; however, this statement should be conditioned to apply only to head-on collisions at this time. No studies were conducted to determine the behavior of these designs under the conditions of skidding or side impact of the automobile. This is a very important consideration, and future research should be devoted to this subject.

2. The cast aluminum inserts proved satisfactory for remedial action to reduce the impact severity of the steel transformer bases which are already in service. Based primarily on economy, however, this does not appear to be a feasible consideration for new design.

3. While flange-mounted poles may not always produce a collision of such intensity that would cause a fatality, they are not recommended for design because the probability of personal injury in a collision with these poles appears to be quite high. Field experience has shown that the side impact with flange-mounted poles is very hazardous.

4. The steel transformer base is definitely an unsatisfactory design and should not be used in any case.

5. A secondary collision of the pole with the top of the vehicle may normally be expected from collisions at low speeds. Although this is not a desirable characteristic, it is at least an improvement over a fixed base design, such as the steel

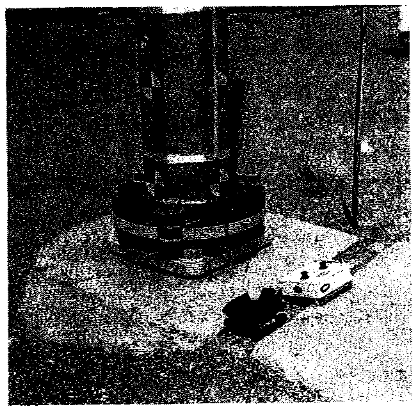
transformer base or the flange mountings, which would not be expected to break away under slow speed conditions.

6. Many design engineers have voiced concern over the trajectory of the pole after impact. In tests with break-away features, it was found that, following impact, the pole generally went in the same direction as the vehicle. Also, it was observed that the top of the pole normally struck the ground near the foundation. In some cases the mass of the base, or the conditions of the pole being held by the vehicle, caused a forward acceleration of the pole, and the pole would travel a considerable distance following the impact.

Development of Multi-Directional Slip Base

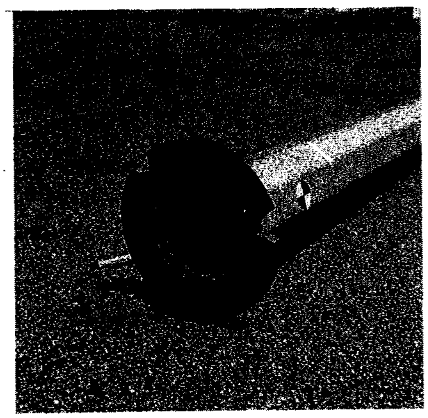
Research Report 75-10, Multi-Directional Slip Base for Break-Away Luminaire Supports, documented the development of a break-away base for luminaire supports. Details of the base are shown in Figure 27. (See Figure 6, 75-10.) The slip base for luminaire supports is composed of two identical plates (Figure 27). Each plate has slots at the apexes of an equilateral triangle. The bottom plate is rigidly attached to the foundation. The top plate is secured to the luminaire support shaft. Bolts are placed in the slots and tightened to provide a clamping force. This configuration produces a base which, by its symmetry, exhibits identical force-slip characteristics for forces applied in any one of the six 60-degree segments.

Laboratory Investigations. A laboratory investigation was performed to determine the effects of slot angle and the line of action (action

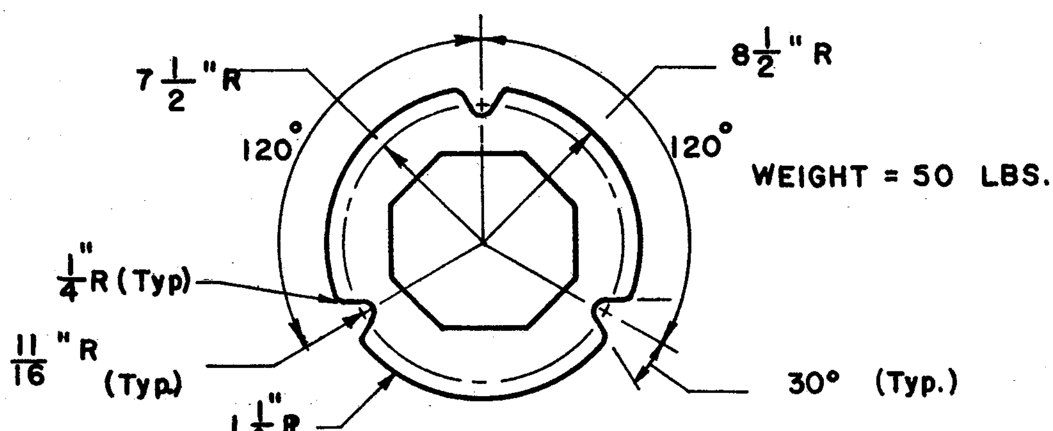


(a)

(b)



(c)



(d)

Figure 27. Details of base for tests S2 & S3.

of incidence) of the impact force on slip behavior. This investigation was conducted using three small bases (approximately 1/4 scale) and a pendulum-type impact device. The three bases with slot angles of 20, 25, and 30 degrees were tested at 0, 30, and 60-degree angles of incidence. Similar results were obtained at 0 and 60-degree angles of incidence, verifying the multi-directional properties of the slip-base.

Full-Scale Field Tests. To validate the concept for service structures, two full-scale crash tests were conducted. Both tests used a 40-foot shaft for a 45-foot luminaire mounting height. Test S2 employed a 3400-pound vehicle, an initial collision velocity of 38.3 mph, with the vehicle striking the support perpendicular to the plane of the arm. In Test S3, the vehicle weighed 3500 pounds, impacted at 35.7 mph, and struck the support at 60 degrees to the plane of the arm. The base bolts for each test were torqued to 1000 in.-lb. initial tension, which corresponds to a force of 2000 pounds for the 1 1/4-inch diameter galvanized bolts used. Galvanized washers were used on the top, bottom, and between the plates.

Test Results. The qualitative data derived from observations of Test S2 are summarized in Figure 28. Figures 28a and b show the support before and after impact, while Figures 28c and d illustrate vehicle damage. Figure 28e shows the final position of the support, the base bolts, and the luminaire. The support landed with its longitudinal axis approximately in line with the vehicle path and did not contact the vehicle after initial collision. The vehicle struck the support on a vertical line through the left front headlight. The headlight was not broken, and the total vehicle damage was minor.

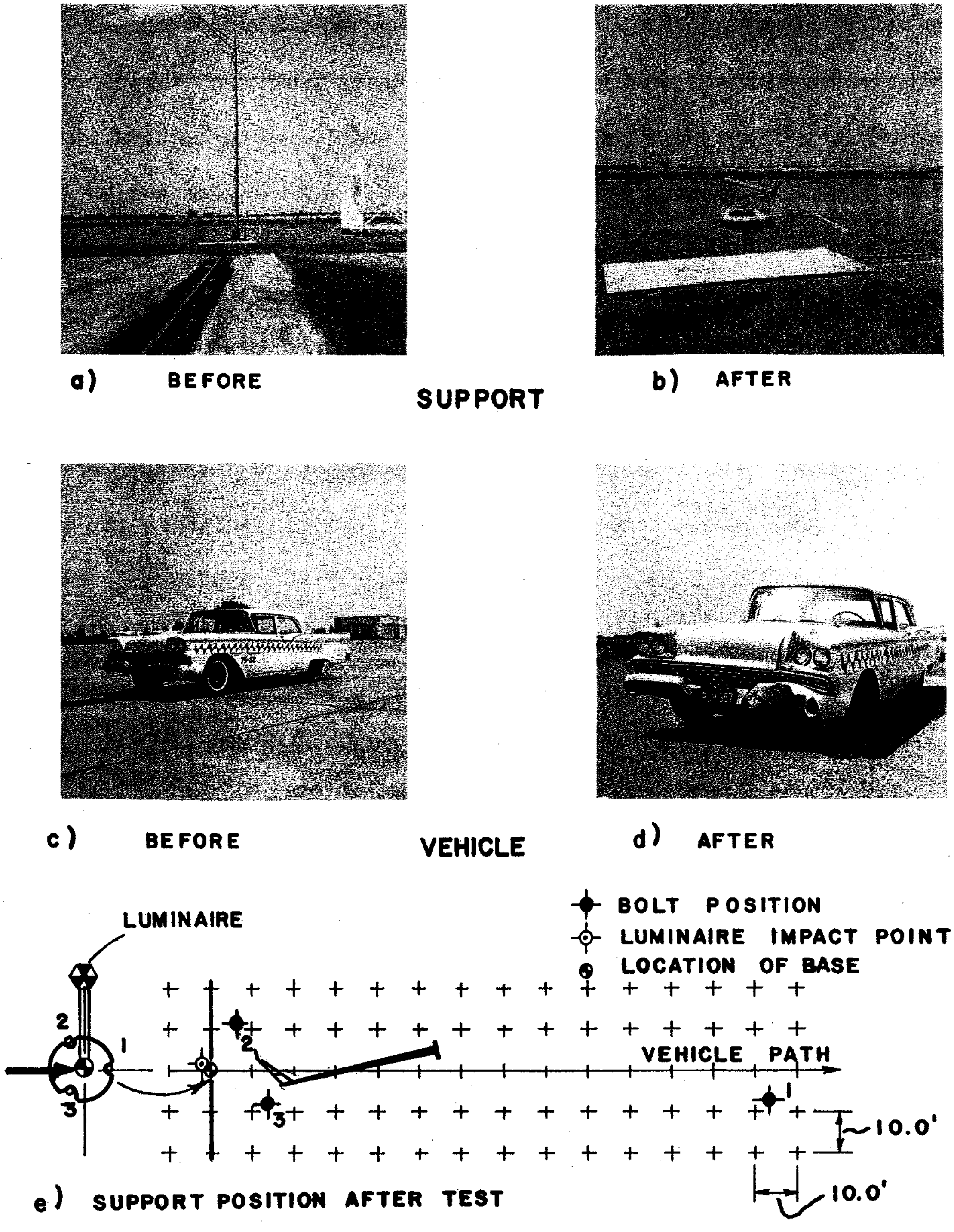


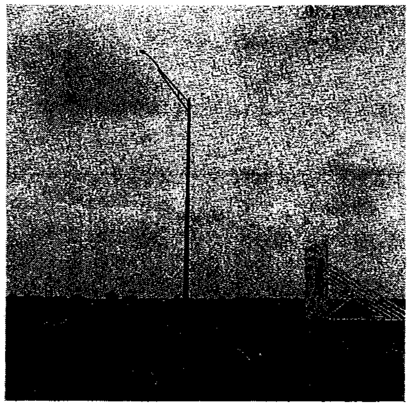
Figure 28. Test S2.

The qualitative data derived from observations of Test S3 are summarized in Figure 29. The impact and post-collision behavior of the support was similar in both tests. Once again, the support did not contact the vehicle after the initial collision and, despite the difference in the angle of incidence (30 vs 0 degrees in Test S2), the support aligned itself with the vehicle path. The vehicle struck the support dead center, crushing the grille and hood. The radiator and engine would have remained operative.

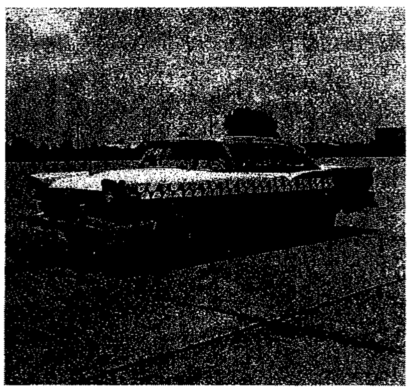
Quantitative information reduced from test instrumentation data are summarized in Table 5 for both tests. In comparison, the collision at the 30-degree angle of incidence was the less severe. This is indicated by the smaller change in vehicle velocity (2.39 mph, as compared to 1.70 mph) and smaller average deceleration (0.42 g compared to 0.74 g). It must be recognized that this is only an indication, since the vehicle's initial velocity, weight, and point of impact were not identical in each test; however, the full-scale tests seem to verify the conclusion drawn from the laboratory investigations.

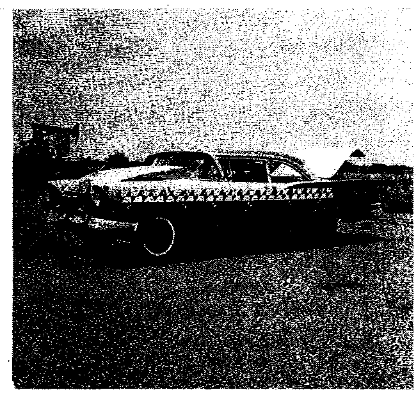
From the information developed in this study, the following conclusions appear to be warranted:

1. The 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 degrees.
3. The optimum collision angle of incidence is 30 degrees measured from a line through the geometric center of the triangular plane form (formed by the location of the three base bolts) to

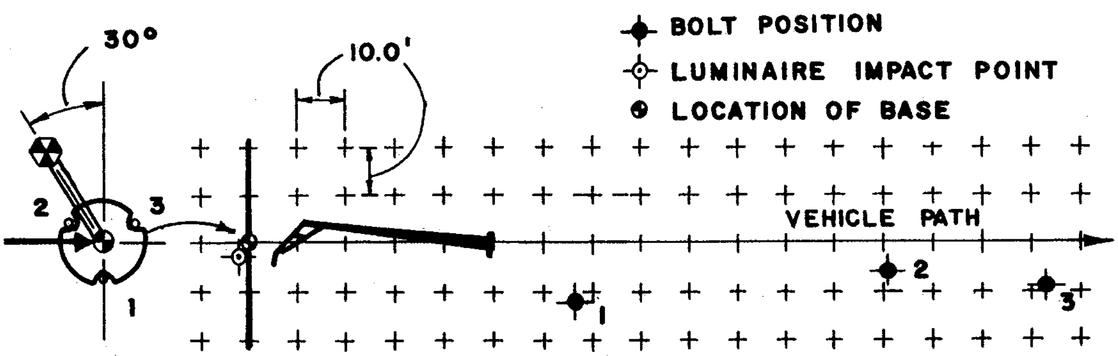


a) BEFORE SUPPORT b) AFTER





c) BEFORE VEHICLE d) AFTER



e) SUPPORT POSITION AFTER TEST

Figure 29. Test S3.

TABLE 5

RESULTS OF DATA REDUCTION

Parameter	Instrument	Test S2	Test 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, $V = V_o - V_f$	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, 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 at event, T_2	Film	1.124 sec	1.167 sec
Average vehicle deceleration $V/32.2\ t_1$	Film	0.74 g	0.42 g
Peak vehicle deceleration	Accelerometer	No data	33.0 g
Rotation of support before ground contact (about longitudinal axis of pole)	Film	270 deg clockwise	220 deg clockwise

the center of a bolt. The support should be oriented such that the most probable vehicle collision path will coincide with this line.

4. In order to keep the base from "walking" under oscillating wind loads, the base bolts should be pre-tightened to not less than 1000 lb/bolt.

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

During the summer of 1969, the California Division of Highways conducted two full-scale vehicle crash tests on the multi-directional slip base for lighting poles. Their conclusions were as follows:

> "Based on the findings of these two vehicle impact tests, the multi-directional slip base is considered to be the most effective break-away device of the five alternatives tested to date (August 15, 1969) by the Materials and Research Department."[3]

Technical Solution of the Impact Behavior of Luminaire Support Assemblies

A mathematical model was developed which can be used to predict the dynamic behavior of a luminaire support assembly when struck by a vehicle. The support model is assumed to be a rigid body under the action of constant and time-dependent forces. The vehicle is assumed to be a spring-mass system having a single degree of freedom and being able to contact the support at any angle in its plane of travel. The forces that act on the post are the gravity force, the spring force due to the vehicle impact, and the normal and frictional base forces. The only constant force is gravity, and no particular form is assumed for the normal and frictional forces.

The response of the post system is governed by two sets of differential equations. The first set predicts the behavior of the system, while the post and the vehicle are in contact and the forces mentioned previously are present; the second set governs when the post has lost contact with the vehicle and is a rigid body moving in space under the influence of gravity. An exact solution to the set of coupled, nonlinear, ordinary differential equations that govern the motion of this dynamic system is difficult to obtain. A numerical technique was, therefore, used to solve them.

The mathematical model of the break-away post was verified by correlation with test results from a full-scale field test for a case exhibiting planar motion. It was also demonstrated that it can predict, with satisfactory engineering accuracy, the phenomenological behavior for the case of a vehicle striking a luminaire support pole.

Parameter Study. A parameter study was conducted to illustrate the value of the mathematical model and point out the crash-dynamic effects of some of the parameters of the luminaire support assembly. Three different luminaire support posts were employed in the study. They included a 9.5 in. x 4 in. x 36 ft.-8.5 in. steel post, an 8 in. x 6 in. x 30 ft. aluminum post, and an 8 in. x 4 in. x 27 ft.-9 in. steel support post with twin luminaires. The mass of the luminaire was taken to be 35 $lb._m$ and the luminaire support arm, in all cases, was taken to have a length of 10.5 ft. and a mass of 83.5 $lb._m$.

A vehicle having a mass of 3200 $lb._m$ and the dimensions of a 1955 Ford sedan were used for the study. The investigation was carried out for vehicular velocities of 20 and 40 mph. The values of the vehicular approach angle used in the investigation were 0, 15, and 30 degrees. The support was assumed to be located 10 feet off the edge of the pavement.

<u>The Effect of the Vehicular Velocity</u>. For a vehicular velocity of 20 mph the support post, with one exception, strikes the vehicle before striking the ground. For a velocity of 40 mph the support assembly clears the vehicle in all cases. The overall behavior of the support post assembly for the two vehicular velocities is very similar. In the cases for 20 mph, the slower-moving vehicle imparts less energy to the support assembly and causes it to encounter the vehicle before striking the ground.

<u>Effect of the Vehicular Approach Angle</u>. The study showed that an increase in the vehicular approach angle caused the support post assembly to have a smaller absolute displacement parallel to the pavement edge and a larger translation in the direction normal to the pavement edge and toward it.

<u>Observations</u>. It is clear from the limited number of cases studied that, regardless of the vehicle speed, type of post used, or vehicle approach angle, the tendency is for the single luminaire support arm to have a clockwise rotation (viewed from above) about the longitudinal axis of the shaft. This rotation causes the support arm to rotate in a direction away from the roadway after the post is impacted.

For the case involving a support post with twin luminaires, it was shown that the tendency is for the rotation to be counterclockwise.

The correlation of the mathematical model with data obtained from the full-scale crash tests demonstrates the feasibility of the application of the model to the luminaire support post problem.

Fatigue Analysis of the Cast Aluminum Base

Wind-induced vibration is a common, though not always readily apparent, phenomenon occurring in roadway lighting structures. In many cases it is insignificant, while in other cases it might be responsible for lamps becoming loose in their sockets or cause a fatigue failure in the luminaire or its support structure. This problem was investigated as a part of Research Study 2-8-64-75 to determine its significance in roadway lighting practices.

In this study, vibration due to the aerodynamic characteristics of the pole were investigated, together with their effects on the fatigue life of a cast aluminum transformer base and a cast aluminum shear base. The objectives were: (1) to develop a computer program, from a mathematical model, to be used in determining the dynamic response of light supports subjected to steady winds, (2) to determine the dynamic response of two typical light supports, with luminaires attached for wind velocities between 0 and 50 miles per hour, and (3) from the response to determine if a fatigue failure will occur in the cast aluminum transformer base or the cast aluminum shear base.

Figure 30 illustrates a luminaire structure representative of many of the support structures used in roadway lighting. Shown in Figure 31 is the idealized structure, where the continuum is lumped into discrete masses interconnected by weightless elastic springs. The number of discrete masses selected for this study represents a compromise between an exact representation of the real structure, which theoretically requires an infinite number, and the number of calculations necessary to reach a solution, which increases with increasing numbers of masses.

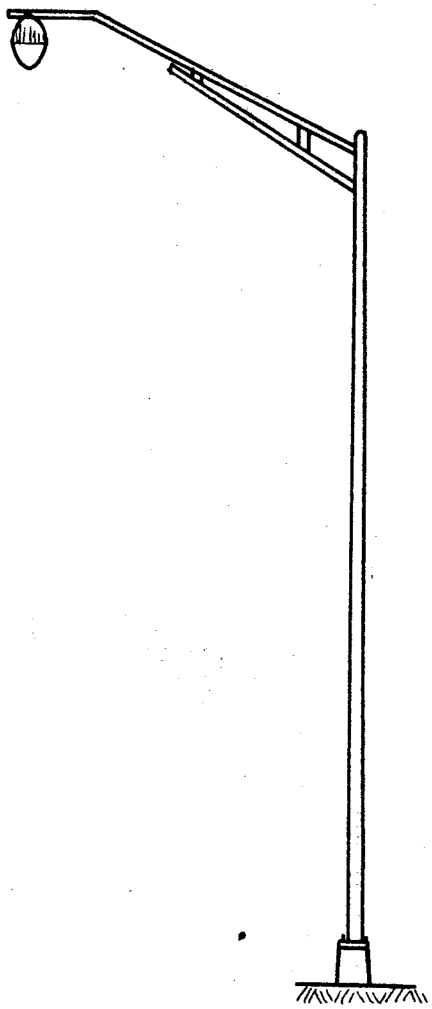


FIGURE 30. TYPICAL LUMINAIRE STRUCTURE

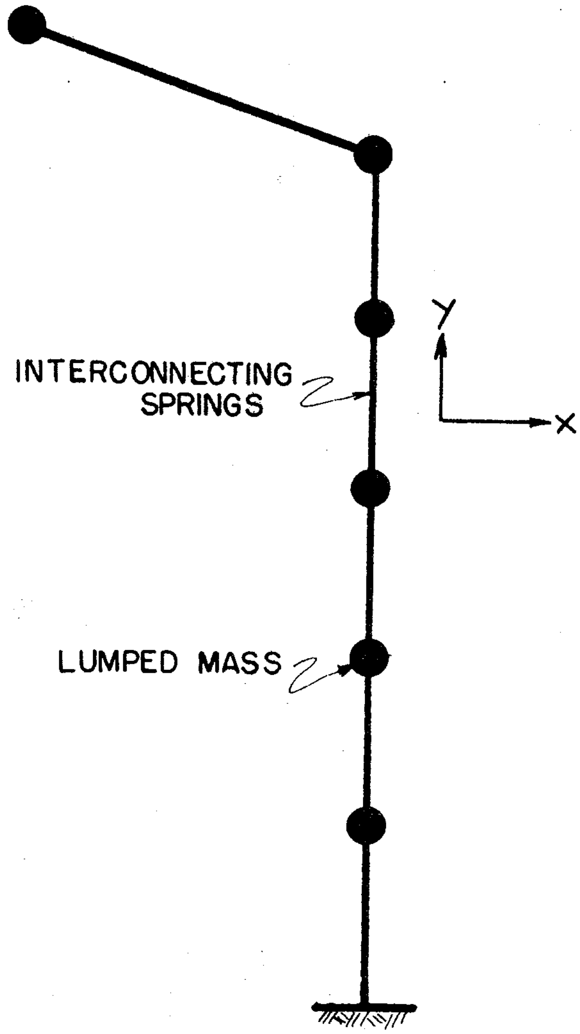


FIGURE 31. IDEALIZED POLE

For the purpose of this investigation, only motions in the plane of the pole and mast (X-Y plane) were considered. Observations of luminaire structures in their natural environments indicated this to be the plane in which the structure reached its most severe vibration.

Shown in Table 6 are the properties of the two structural configurations that were considered. These two are felt to be representative of the many different types in use.

It was not within the scope of this study to verify the mathematical model with extensive full-scale tests. A full-scale outdoor test was made, however, on pole "B" (See Table 6), in which response frequencies were measured during winds of 25 to 35 miles per hour. The full-scale tests compared very favorably with that predicted by the mathematical model.

Based on the results of the investigation, it appears that vibrations in light pole standards will not result in a fatigue failure of the cast aluminum base. The minimum factor of safety of 5.40 found for the two pole configurations considered forms a basis for this conclusion.

It was also demonstrated that the mathematical model of the luminaire support structure can be used to determine the dynamic response of light supports under wind loading.

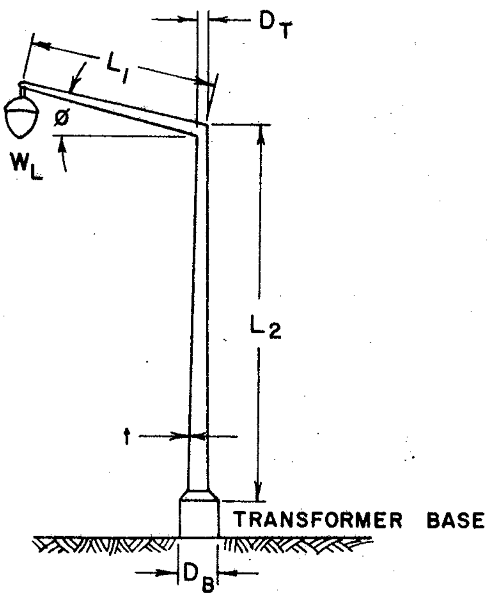


TABLE 6. POLE PROPERTIES

Property	Pole A	Pole B
Material	Aluminum	Steel
Length, L_1	6 ft.	15.5 ft.
Length, L_2	30 ft.	35 ft.
Angle, ϕ	30 degrees	18.5 degrees
Luminaire Weight, W_L	67 lbs.	50 lbs.
Diameter at Top of Pole, D_T	4.5 in.	4.25 in.
Diameter at Base of Pole, D_B	7.5 in.	9.00 in.
Pole Thickness, t	0.188 in.	0.125 in.
Damping coefficient*, c	5%	5%

*Expressed as a percent of critical damping.

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3. "Report of the Results of Two Full-Scale Impact Tests of the Multi-Directional Slip Base for Lighting Supports," California Division of Highways, Project 636408, August 1969.