

Interim Progress Report on Supplementary
Studies in Highway Illumination

by

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and

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

PREFACE

This interim progress report summarizes the findings of three years of research in highway illumination and the current progress of Research Study 2-8-64-75. This research is being conducted by the Texas Transportation Institute in cooperation with the Texas Highway Department and the U. S. Department of Transportation, Federal Highway Administration, Bureau of Public Roads.

The various phases of the illumination research are covered in detail in five interim reports. These reports are listed as follows:

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

Research Report 75-3, "An Interim Report on Roadside Sign Visibility," by Ned E. Walton and Neilon J. Rowan.

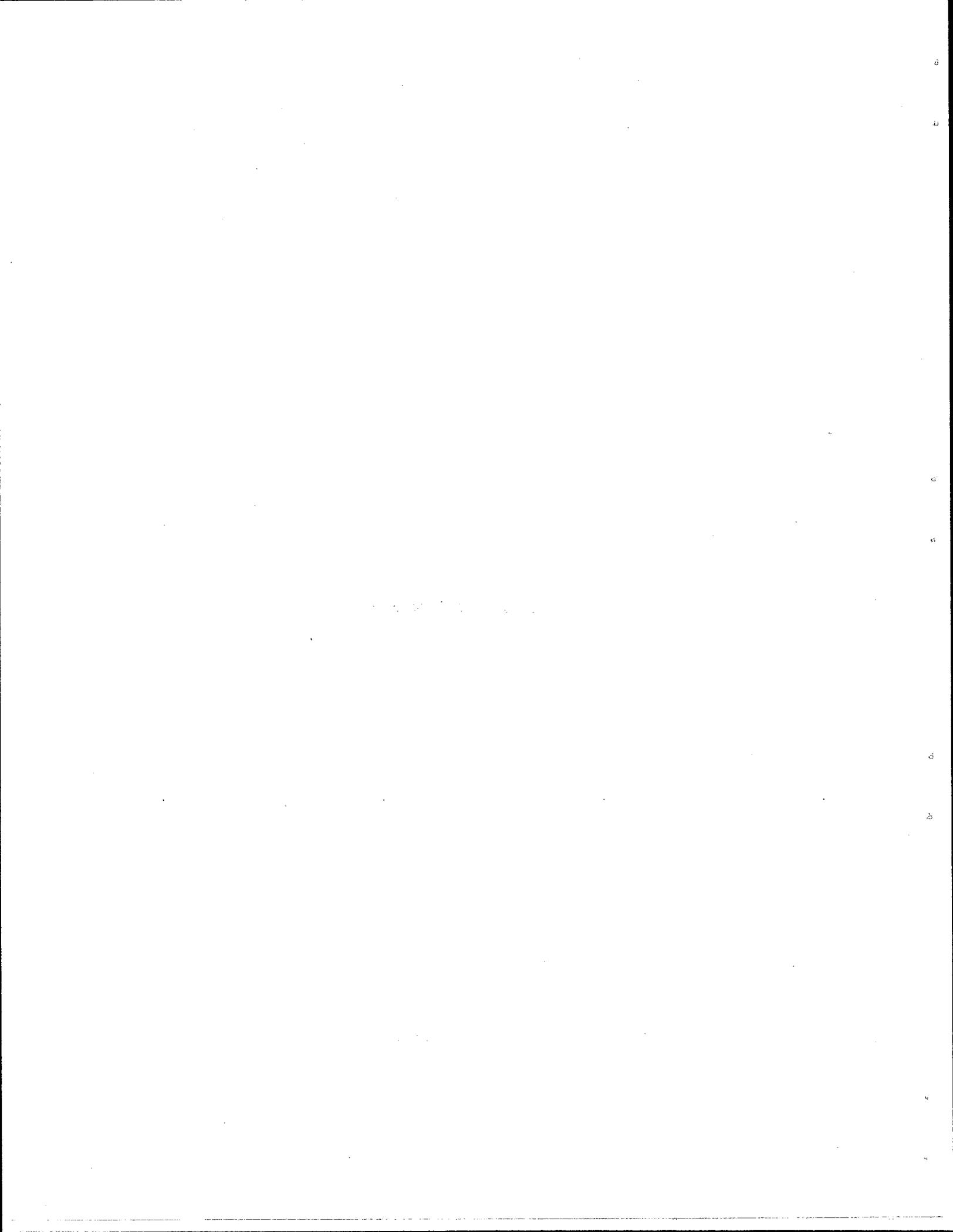
Research Report 75-4, "Photometric Studies of the Austin Moonlight Tower Lighting Systems," by Ned E. Walton and Neilon J. Rowan.

Research Report 75-5, "An Interim Report on a Study of Disability Veiling Brightness," by Ned E. Walton, Neilon J. Rowan and Hans C. Jensen.

Research Report 75-6, "Photometric Studies of Cutoff Luminaire Designs," by Ned E. Walton and Neilon J. Rowan.

Summaries of the research reports, unpublished research results, and current research progress are embodied in this interim report.

O B J E C T I V E S



OBJECTIVES

As our Nation's highways become more complex and heavily traveled, the need for satisfactory driving environments at night becomes more pronounced. This need is currently being studied by the Texas Transportation Institute in cooperation with the Texas Highway Department and the U. S. Department of Transportation, Federal Highway Administration, Bureau of Public Roads. Research Study 2-8-64-75, "Supplementary Studies in Highway Illumination," was initiated by the Institute in 1964 with the ultimate goal of providing illumination design criteria for satisfactory night driving environments.

The overall objective of the illumination research can be stated as follows:

"The study of existing practices in continuous and safety 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 objectives of the illumination research can be broken into the following:

1. To establish the most efficient and functional continuous lighting system design criteria for multi-lane freeway type facilities.
2. To investigate methods of illuminating interchanges (including high-level floodlighting) and to develop design criteria for interchange lighting.

1. The first part of the document discusses the importance of maintaining accurate records of all transactions. This is essential for ensuring the integrity of the financial statements and for providing a clear audit trail. The records should be kept up-to-date and should be easily accessible to all relevant parties.

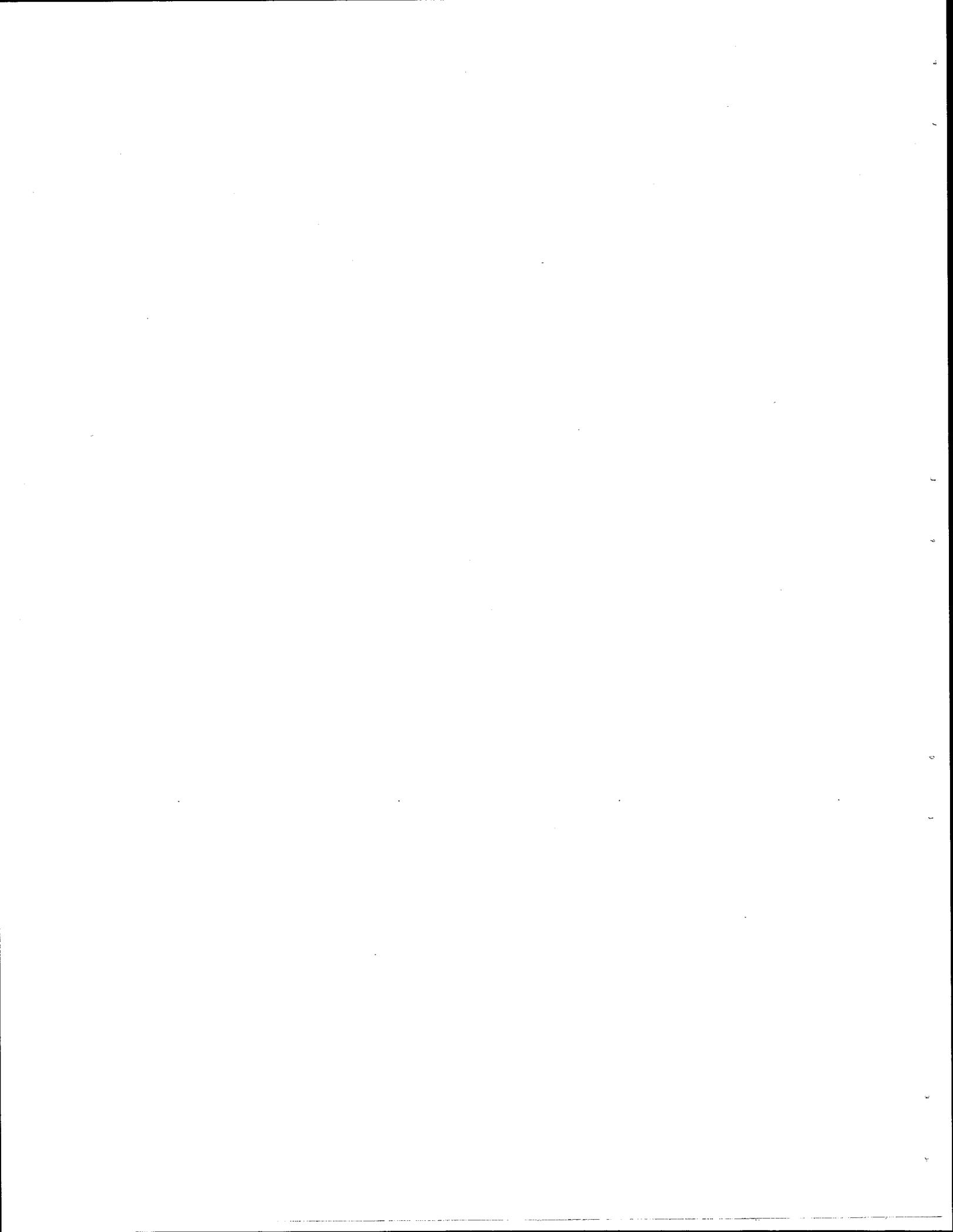
2. The second part of the document outlines the procedures for handling discrepancies. It is important to identify any errors as soon as they are discovered and to investigate the cause of the error. Once the cause has been identified, the necessary steps should be taken to correct the error and to prevent it from recurring.

3. The third part of the document discusses the importance of regular communication between all parties involved in the financial process. This includes the management, the accounting department, and the external auditors. Regular communication helps to ensure that everyone is aware of the current status of the financial statements and any issues that may arise.

4. The fourth part of the document outlines the responsibilities of each party involved in the financial process. It is important to clearly define the roles and responsibilities of each party to ensure that everyone is working towards the same goal. This helps to avoid confusion and ensures that the financial statements are prepared accurately and on time.

5. The fifth part of the document discusses the importance of maintaining a strong internal control system. This system should be designed to prevent and detect errors and fraud. It should be regularly reviewed and updated to ensure that it remains effective. A strong internal control system is essential for ensuring the reliability of the financial statements.

C O M P L E T E D R E S E A R C H



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 foot-candles.

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 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 experiment 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 experiment design for each manufacturer.

Computer techniques were used to develop photometric measures and iso-footcandle curves 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 30- to

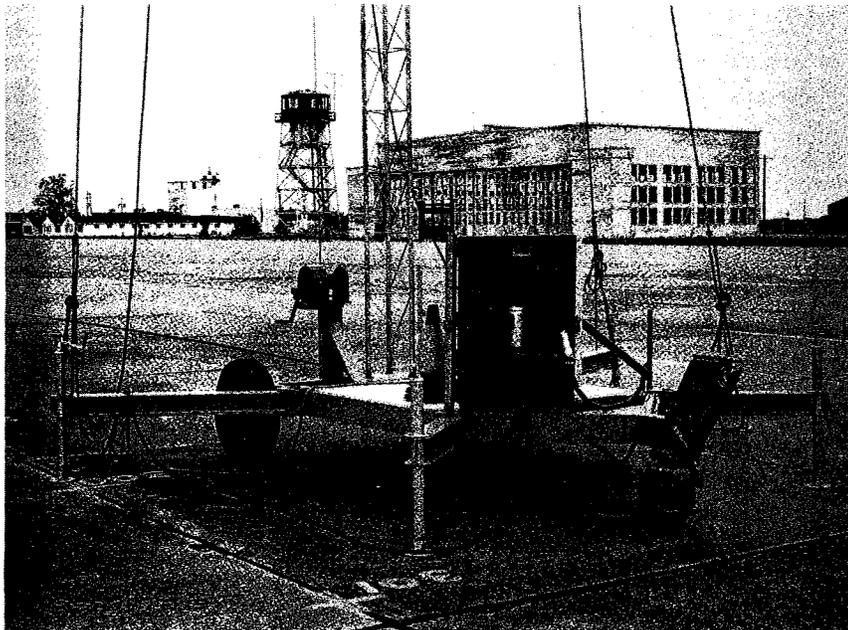
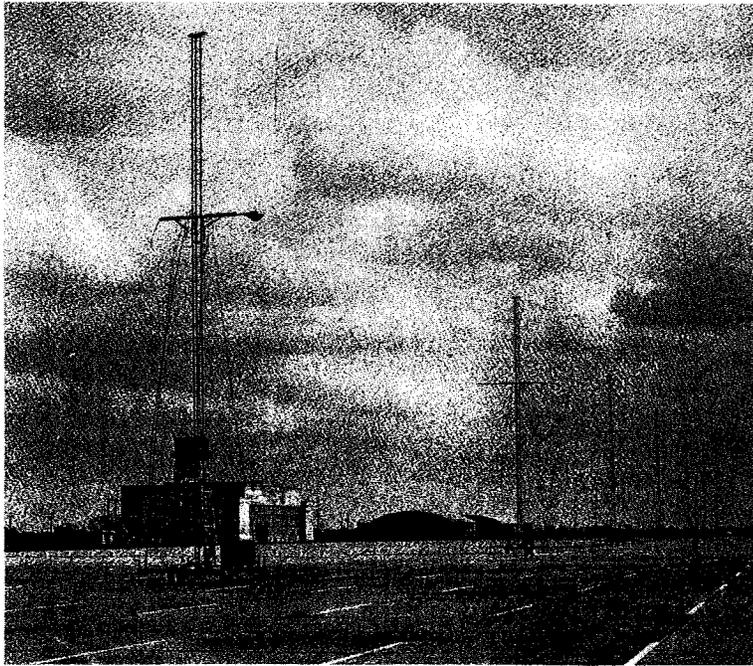


Figure 1. Portable lighting towers.

Table 1

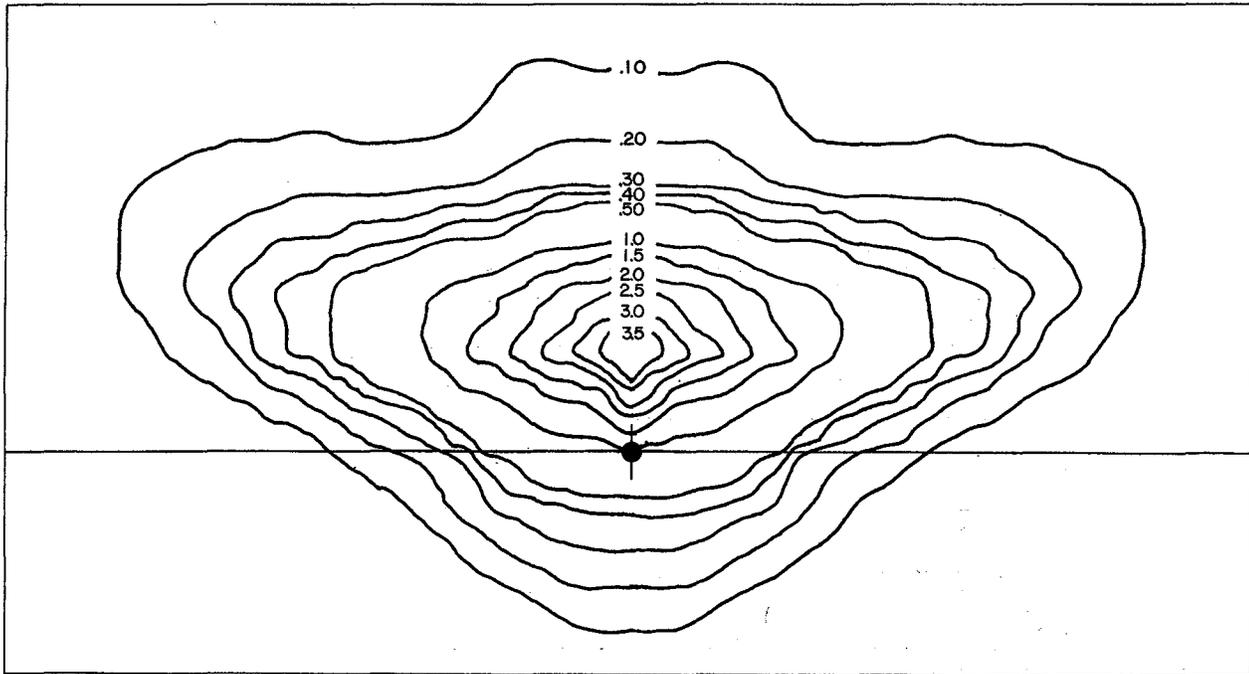
Experiment Design

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

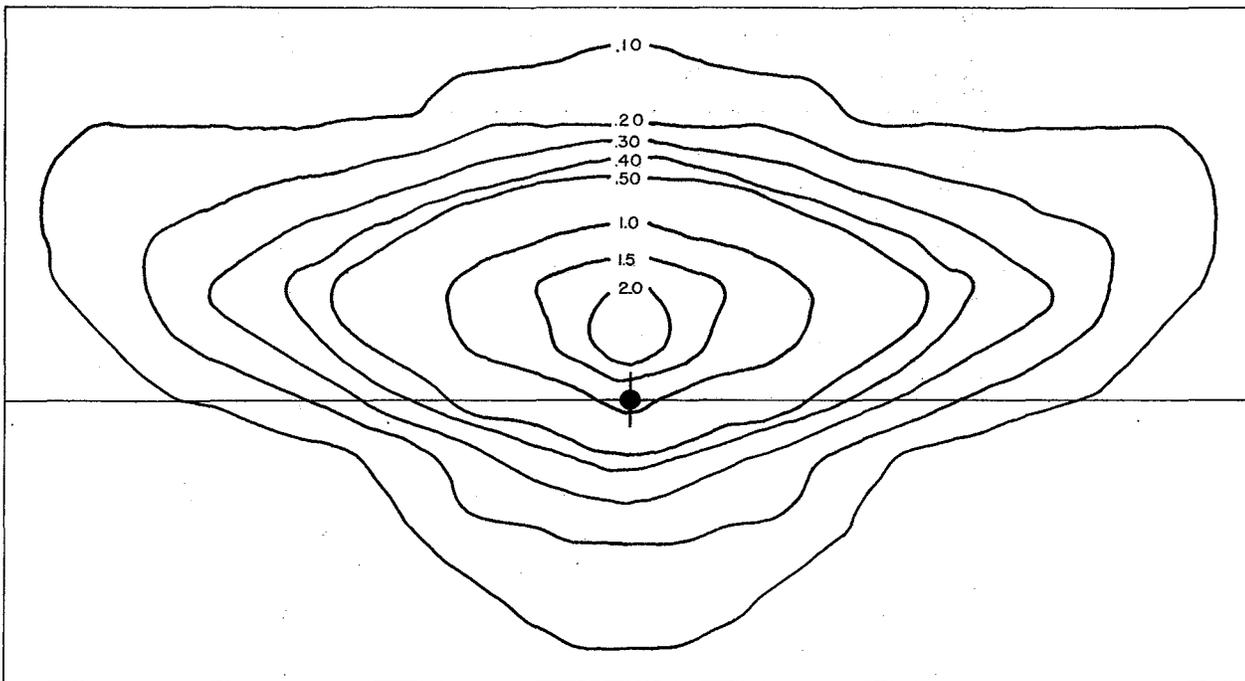
Other Parameters In The Experimental Design

- 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 III₄
MOUNTING HEIGHT: 30'



ISO-FOOTCANDLE CURVE
SINGLE LUMINAIRE

LUMINAIRE: 400 WATT, TYPE III₄
MOUNTING HEIGHT: 40'

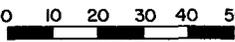
SCALE:  0 10 20 30 40 50
FEET

Figure 2. ISO-Footcandle charts of individual luminaires.

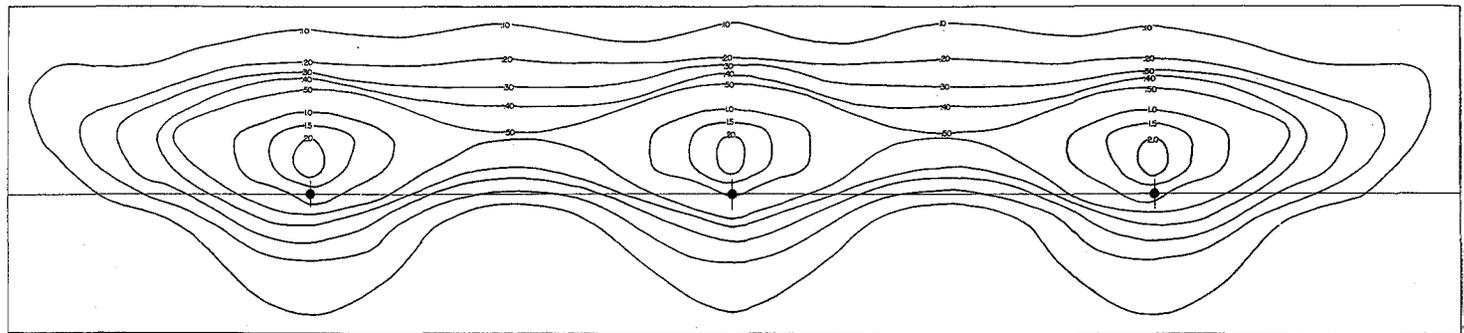
40-foot mounting height. Figure 3 shows the light distributions for several systems. It is significant to note that most of the contour lines within these systems are essentially parallel to the traffic lanes, which indicates that the systems provide uniform lighting for any particular lane.

The effects of system configuration on the resultant light distribution of a roadway lighting system can be summarized as follows:

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).
2. The uniformity of illumination on the roadway was directly 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.
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 directly 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 systems and the photometric characteristics being used as criteria.

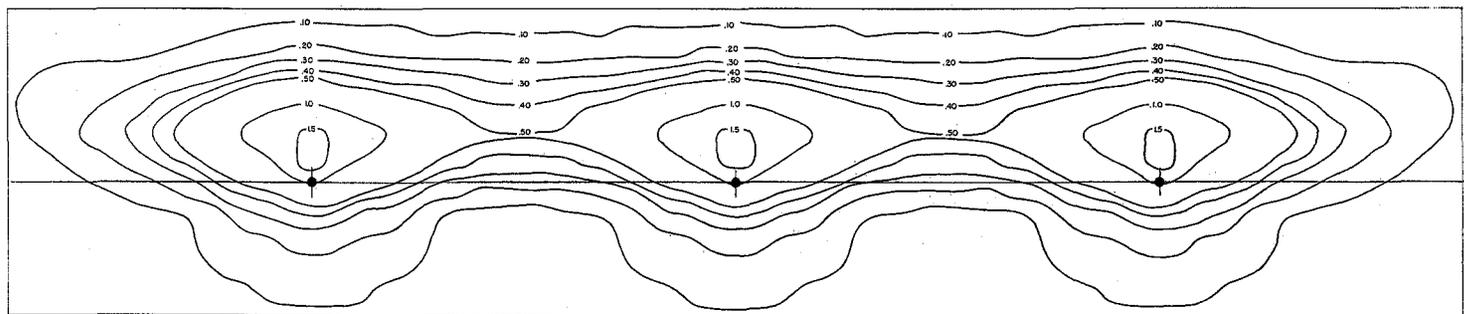
This research has shown uniformity of illumination to be a very important factor in roadway lighting design. Visual evaluations of these systems have suggested that any reduction in visibility due to a lower average illumination can usually be more than compensated for by an apparent increase in visibility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



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

ISO-FOOTCANDLE CURVE
ONE-SIDE LIGHTING

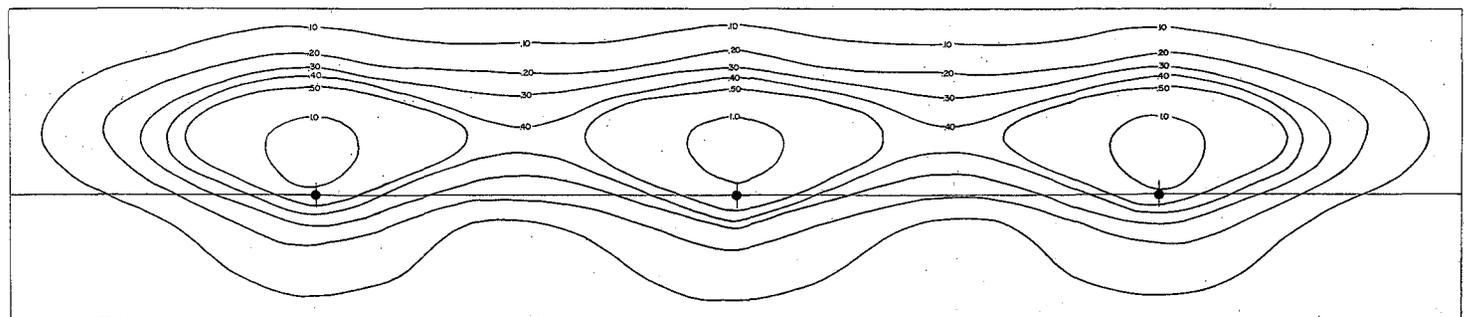
LONGITUDINAL SPACING: 200'



LUMINAIRE: 400 WATT, TYPE III,
MOUNTING HEIGHT: 45'

ISO-FOOTCANDLE CURVE
ONE-SIDE LIGHTING

LONGITUDINAL SPACING: 200'



LUMINAIRE: 400 WATT, TYPE III,
MOUNTING HEIGHT: 50'

ISO-FOOTCANDLE CURVE
ONE-SIDE LIGHTING

LONGITUDINAL SPACING: 200'
SCALE: 0 20 40 60 80 100
FEET

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

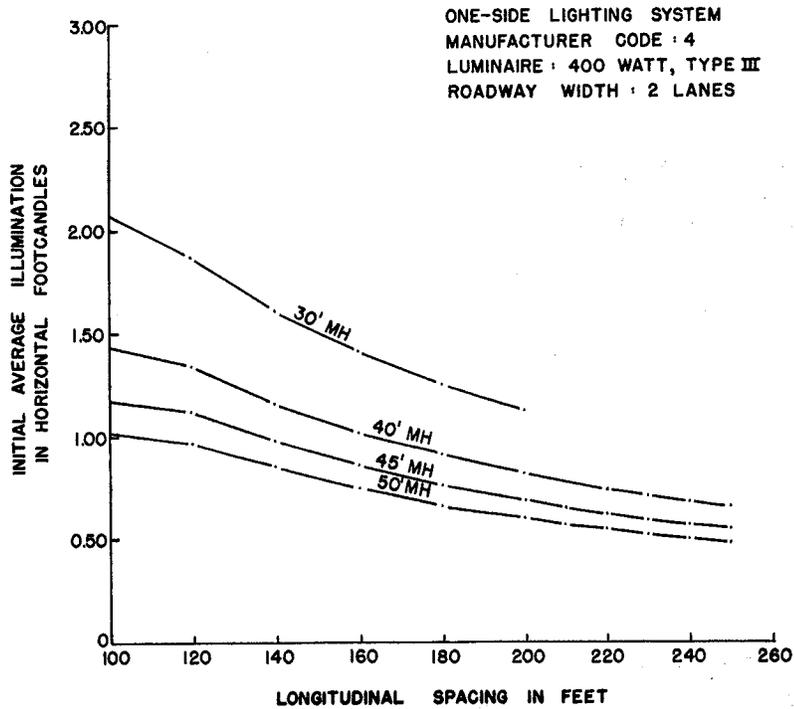


Figure 4a. Initial average illumination vs. longitudinal spacing for different mounting heights.

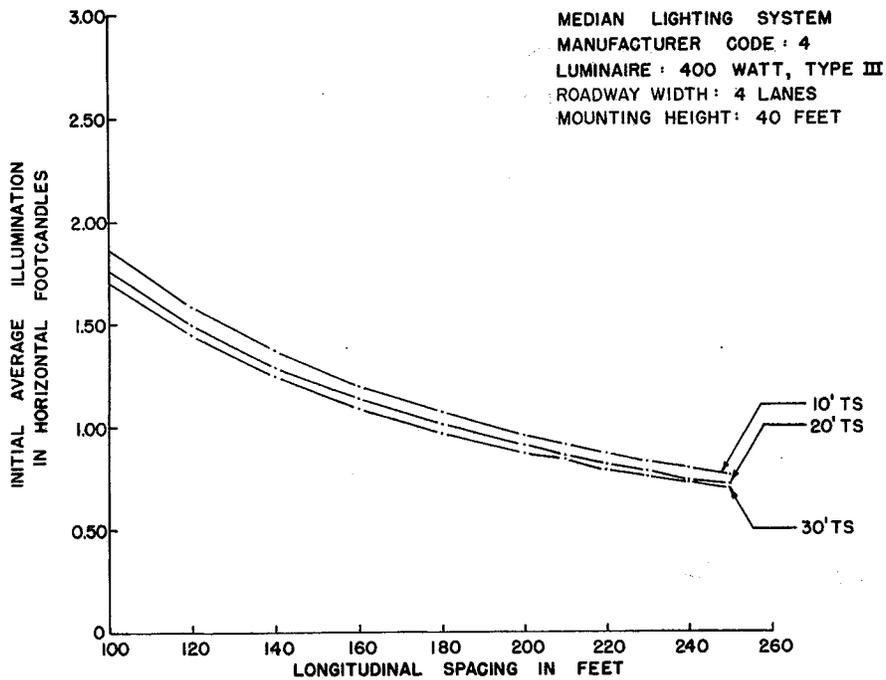


Figure 4b. Initial average illumination vs. longitudinal spacing for different transverse spacings.

Figure 4

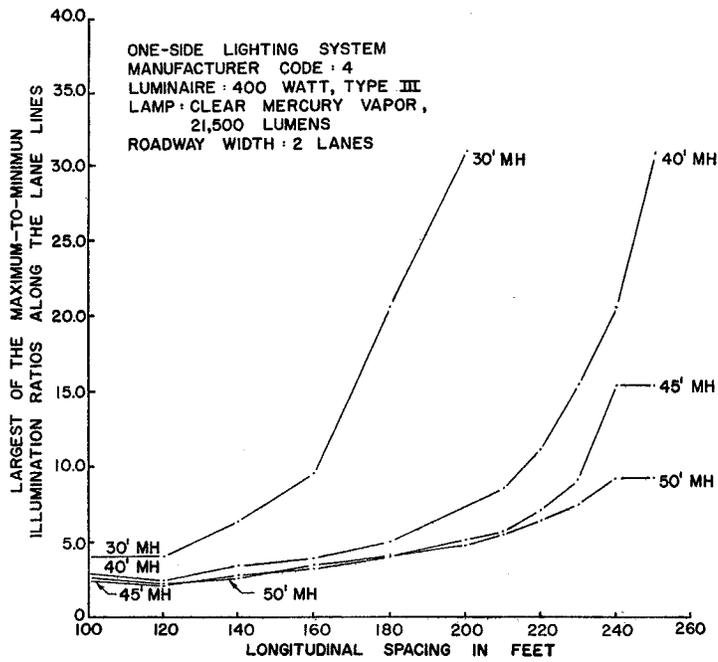


Figure 5a. Ratio of maximum to minimum illumination vs. longitudinal spacing for different mounting heights.

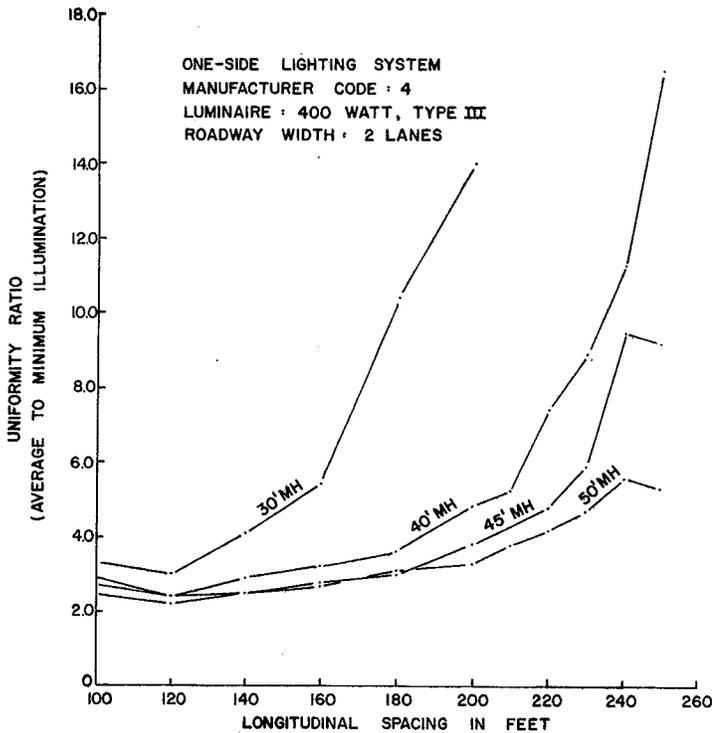


Figure 5b. Uniformity ratio vs. longitudinal spacing for different mounting heights.

Figure 5

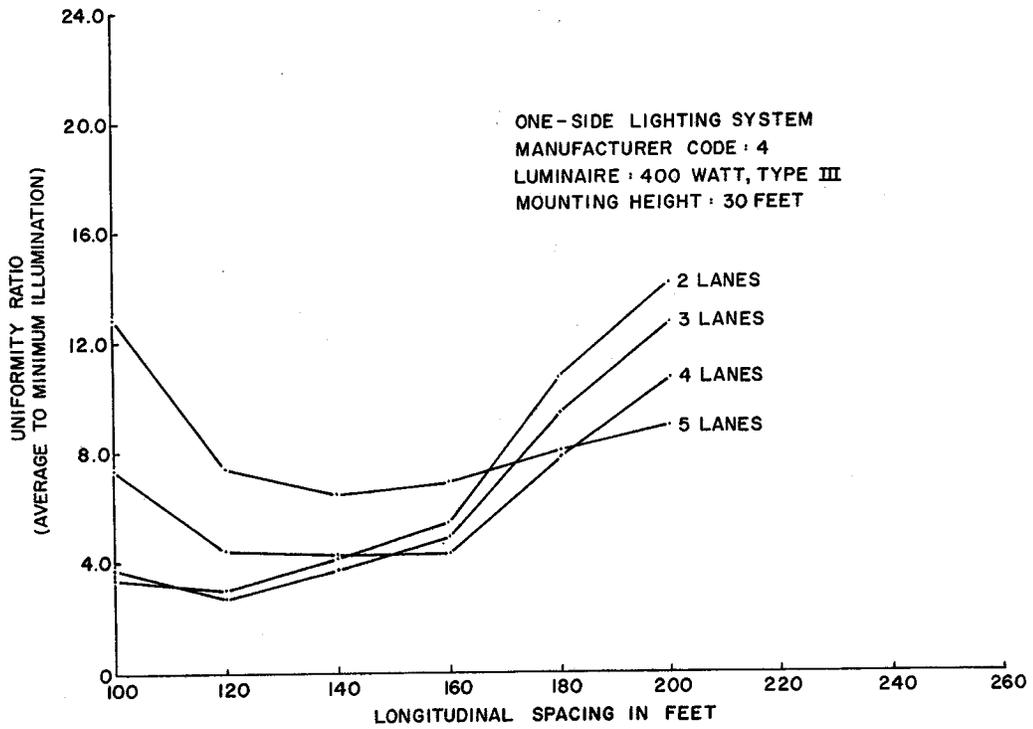


Figure 6a. Uniformity ratio vs. longitudinal spacing for different roadway widths.

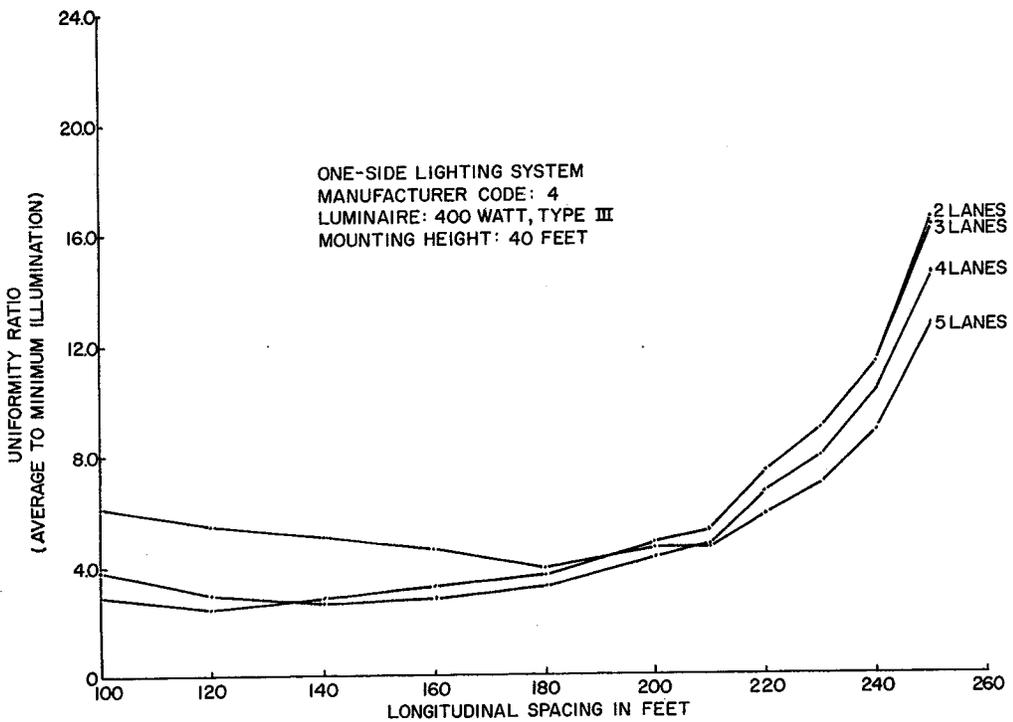


Figure 6b. Uniformity ratio vs. longitudinal spacing for different roadway widths.

Figure 6

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' lanes. The 1000-watt luminaires were mounted on the same towers on longer arms, positioning them five feet out 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.

In 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.

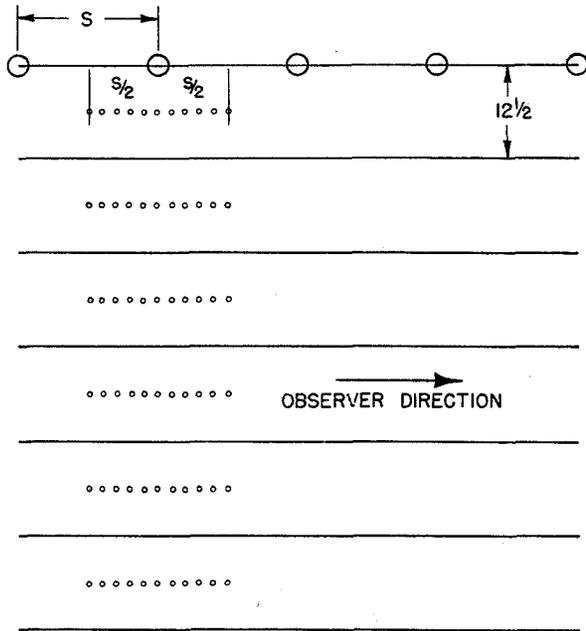
Further studies should be conducted to include measurements of representative tasks, including measurements of task brightness, pavement brightness, and DVB to determine task contrasts and loss of visibility caused by DVB for the systems under consideration.

It is evident that ratings for the effectiveness of roadway lighting in producing good seeing 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.

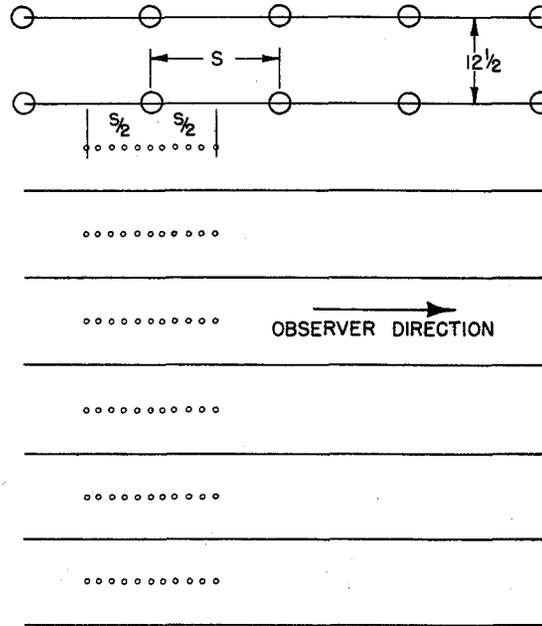
Photometrics of Cutoff Luminaires

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 luminaires, one of the more commonly used designs for freeway lighting.

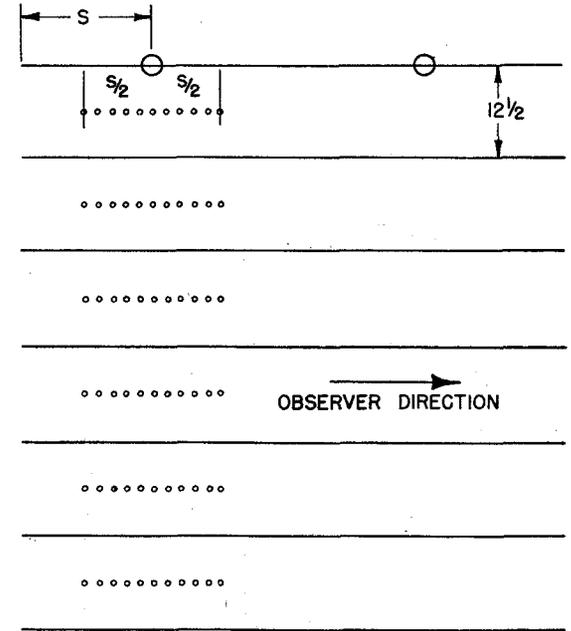
S — LONGITUDINAL SPACING
 ○ — LUMINAIRE POSITIONS
 • — MEASUREMENT POINTS



ONE-SIDE SYSTEMS



MEDIAN SYSTEMS



STAGGERED SYSTEMS

LAYOUT OF THE TEST SITE

Figure 7

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:

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 designs.

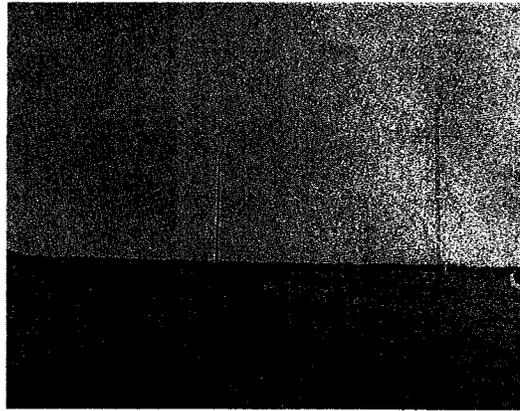
Measurements of horizontal footcandles were made for the cutoff units. The experimental procedure using synthetic or computer-built systems approximated that of the Type III continuous lighting system studies described in an earlier section of this report. In addition, four systems representing the two 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:

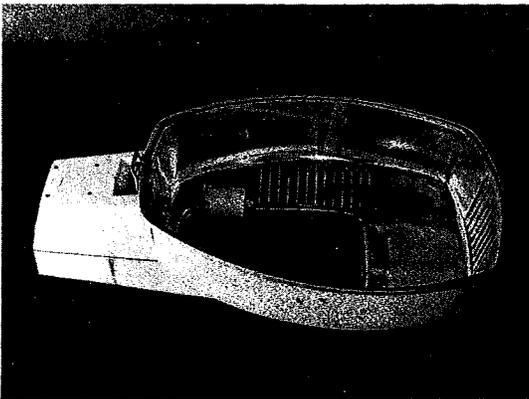
1. The initial minimum illumination was inversely proportional to longitudinal spacing and roadway width (Figure 9).
2. The rate of reduction of initial minimum illumination due to increase in longitudinal spacing and roadway width was inversely proportional to mounting height.
3. The initial average 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.

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

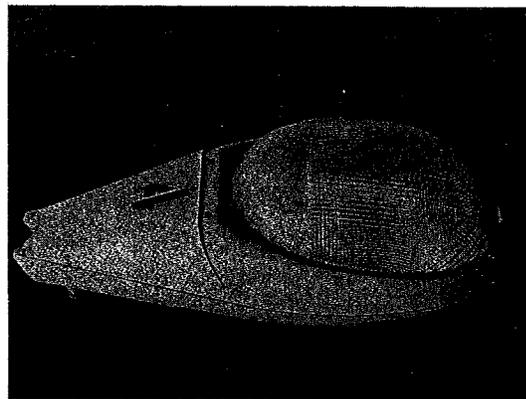
1. To produce systems with similar photometric characteristics, the Type III luminaires can be spaced at longer longitudinal spacings and higher mounting heights than the cutoff luminaires. For example the Type III



Test Facility



Cutoff Luminaire



Type III Luminaire

Figure 8

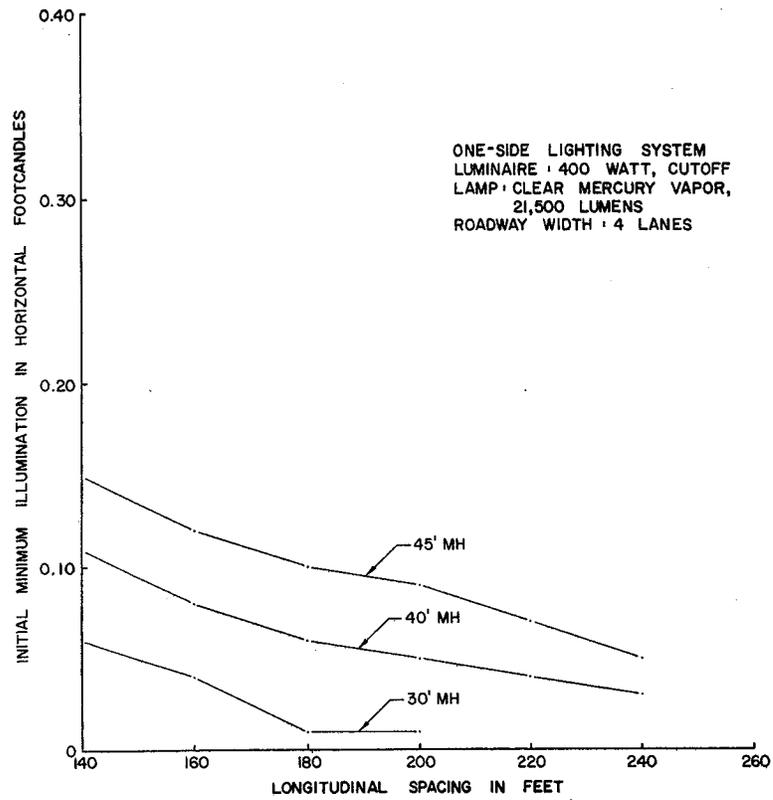
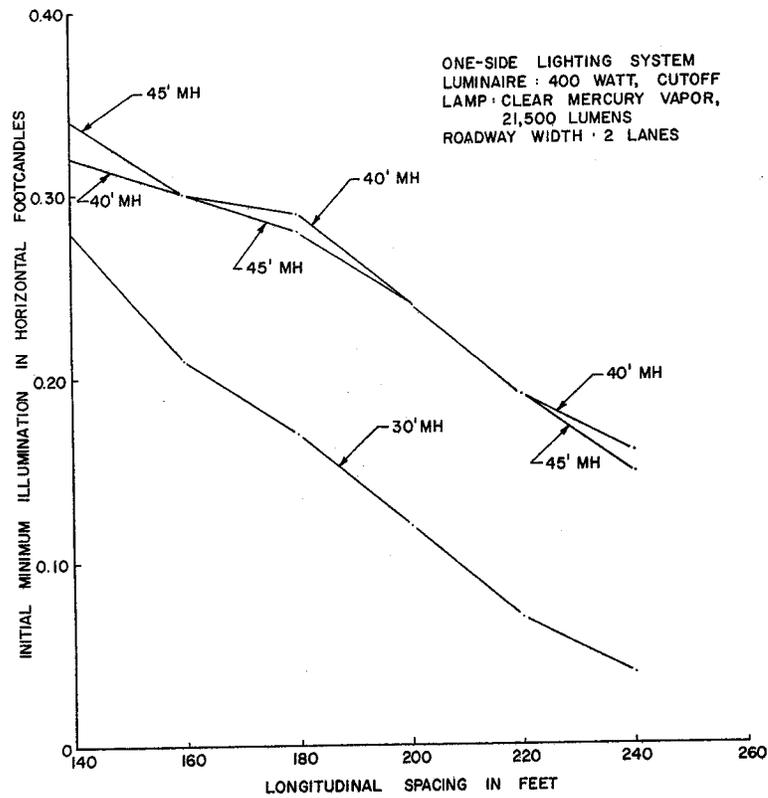


Figure 9. Initial minimum illumination vs. longitudinal spacing for different mounting heights.

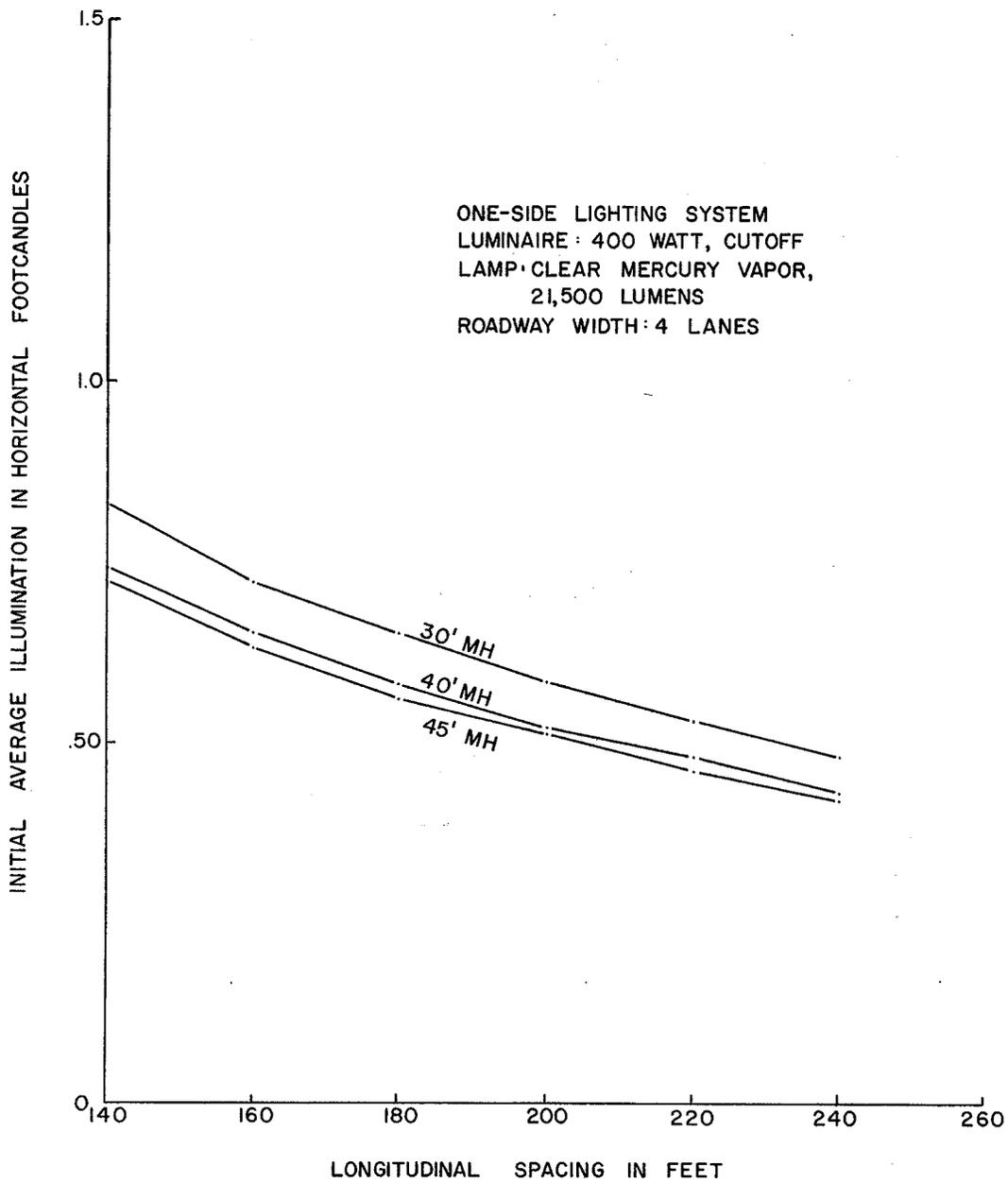


Figure 10. Initial average illumination vs. longitudinal spacing for different mounting heights.

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 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 has 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 ratio on divided roadways of 4, 6, and 8 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 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 the roadway widths 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. However, should these problems be eliminated or reduced, the high-intensity lamp design could play a big 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 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

LEGEND

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

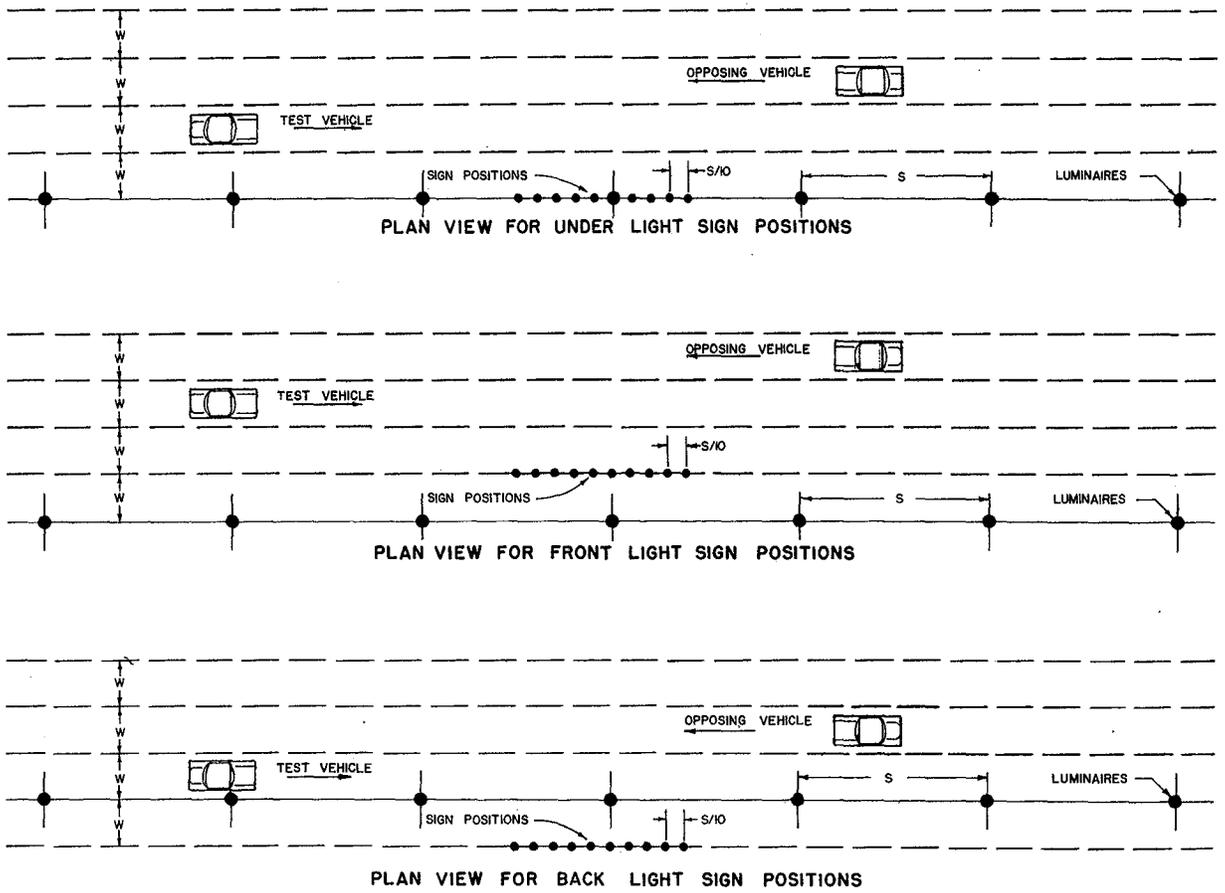


Figure 11

letters on a white reflectorized background, were used. One of these signs is shown in Figure 12 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.

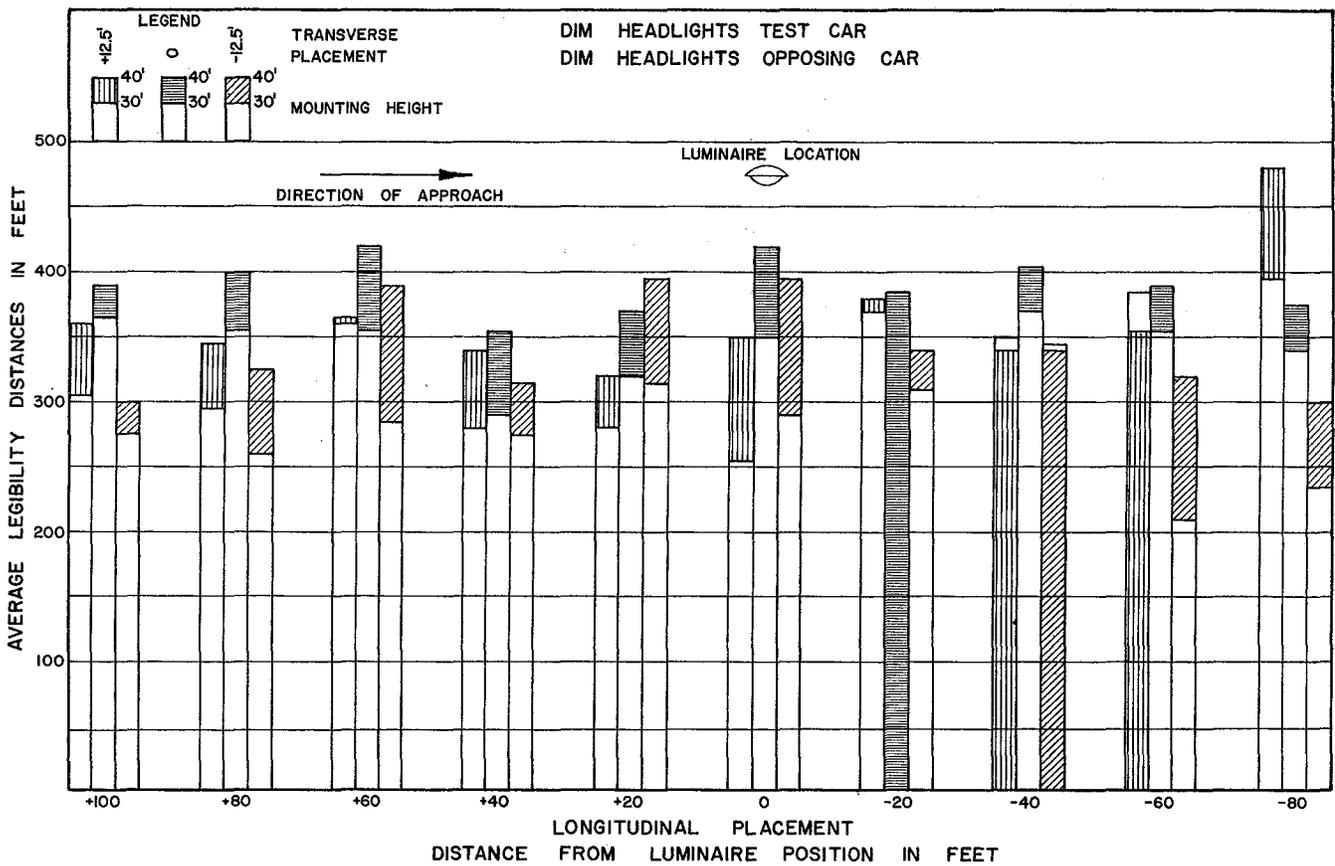
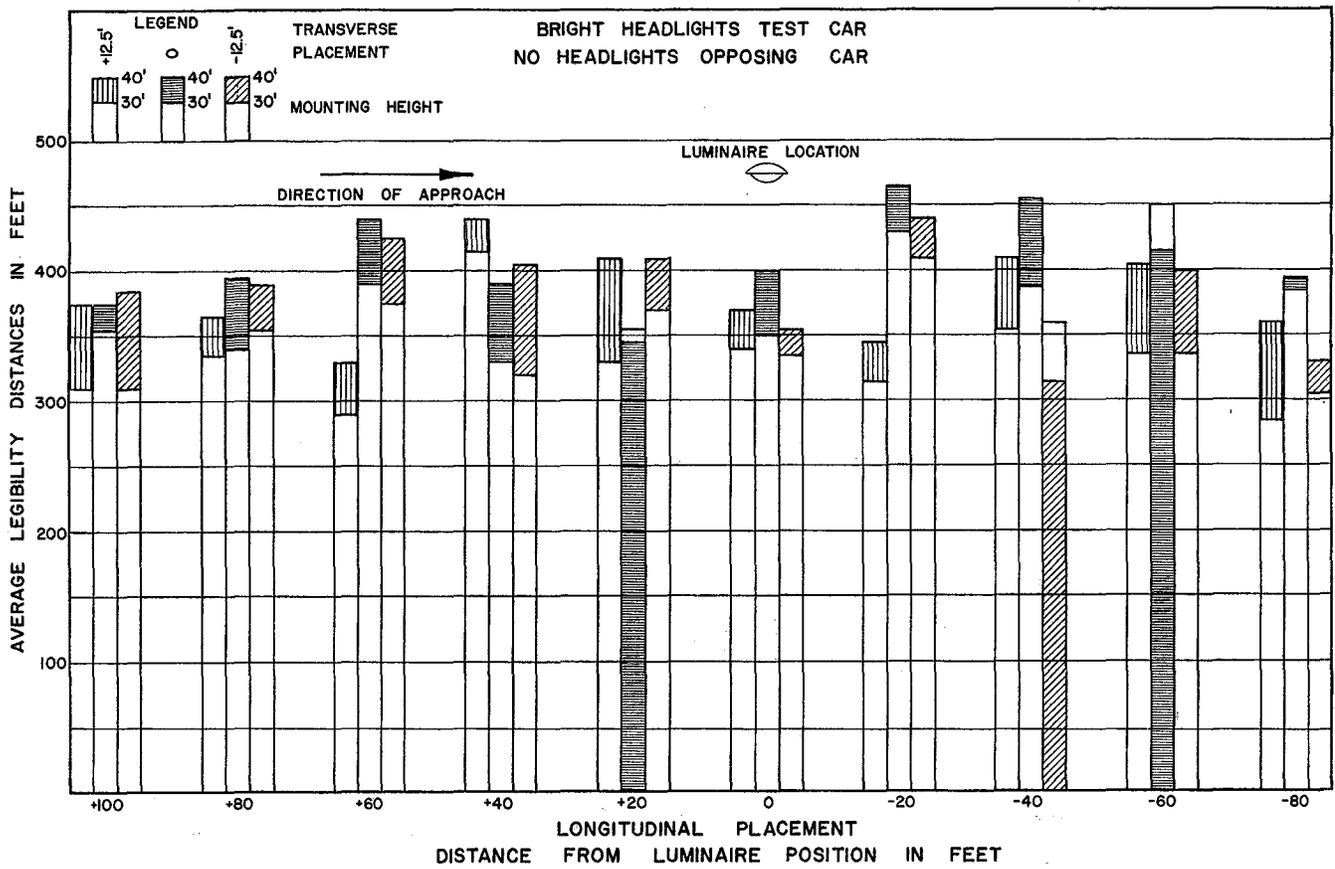
From studying the selected systems and associated parameters, the following observations were warranted:

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 in 40-foot mounting heights or in 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



Figure 12. Portable sign frame and test sign.



EFFECTS ON LEGIBILITY DISTANCE FOR CONDITIONS SHOWN

Figure 13

from 20 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.

INTERCHANGE LIGHTING

High-Level Area Lighting

Creating a satisfactory environment for safe and efficient nighttime driving is one of the objectives of the highway designer. To create this environment on our modern highways where traffic speeds and densities are often high, and where driver decisions are frequent, it is generally necessary to use some form of artificial lighting to supplement the headlight system of the automobile. For freeways and other access-controlled facilities, mercury vapor luminaires in a conventional geometric configuration will normally illuminate the roadway and adjacent areas sufficiently because visual cues to the driver are generally limited to this immediate area. However, in the interchanges of these modern highways, it is necessary that the driver have a view of the entire area, similar to daylight conditions, rather than just the roadway immediately in front of him. Such an environment is necessary so that the driver can plan the maneuvers to be executed in a systematic and safe manner. This environment is not always provided by conventional lighting systems where the light sources are mounted on relatively short poles along the side of each roadway in the interchange area.

The complexity of modern interchanges and the presence of roads of greatly varying character entering at different levels require more than conventional lighting can afford. The principal requirements for a satisfactory driving environment are: (1) good seeing conditions to guide motorists through the interchange area; (2) adequate illumination and brightness on the roads enabling motorists to see each other clearly, especially at points where different traffic flows meet; and (3) a feeling of security on the part of the motorists.

For the purposes of lighting freeways and access controlled facilities it has been found that mercury vapor luminaires mounted at 40 to 50 feet and spaced 200 to 300 feet apart adequately illuminate the traveled way and the immediately adjacent areas. These units may be mounted in the median area or along the shoulder with good results. However, mounting the units in the median generally results in a reduction in the number of poles required in the lighting system. The increased mounting heights reduce the glare and thus improve the seeing ability of the driver.

The use of these improved conventional lighting systems in the complex interchange areas does not always provide the most satisfactory means of illumination. First, numerous light sources are required to light each roadway of the interchange satisfactorily. Obviously, this results in higher costs and increases in glare and fixed object hazards. These light sources, when mounted to conform to the various elevations of the interchange, produce glare in the driver's eye and these glare sources are additive. The large number of poles required to support these luminaires are objectionable because of the "forest" which detracts from the appearance and visibility during daylight hours and from the hazard which each presents to the motoring public.

Engineers of the Texas Highway Department have become quite interested in experimental lighting projects in Europe which utilize floodlights mounted on high poles to illuminate an entire interchange area. The first installation of this type was that at the Heerdter Triangle near Dusseldorf. Similar applications of floodlighting have been investigated in this research project.

Floodlighting is not a new concept to the lighting industry. However, its application to roadway lighting is new. The uniqueness of this application is in the reduced level of illumination required for functional efficiency.

As an initial investigation in this research, the Texas Transportation Institute with the cooperation of the city of Austin, Texas, and the Texas Highway Department conducted a photometric study on one of the 150-foot "moonlight" towers in Austin.² The tower used in the study was equipped with six vertical burning mercury vapor lamps mounted in 18-inch radial type porcelain reflectors which were mounted in a 10-foot circle with uniform angular spacings of 60° (Figure 14). Four types of mercury vapor lamps, 400- and 1000-watt, clear and phosphor coated were used in the study, and a GE SL 480-A street lighting meter, designed and calibrated to measure horizontal footcandles was used for the photometric measurements.

A comparison of the four systems was then made on the basis of the horizontal footcandle measurements and iso-footcandle curves were prepared for each system. These were published in an earlier report.²

The principal concern in any lighting system is minimum light intensity within a given area and the uniformity of light within that area. By current Texas Highway Department standards for conventional roadway lighting, 0.10 horizontal footcandle is the minimum acceptable value. During this study, however, it was obvious that the standards for conventional lighting are not applicable to high-level lighting since the 0.10 horizontal footcandle minimum intensity is not indicative of visibility conditions provided by the high-level lighting systems. Simply by observation, it appeared that adequate visibility could be realized with intensity levels of 0.05 footcandle or less. It became apparent that other criteria must be established for judging or evaluating high-level lighting systems.

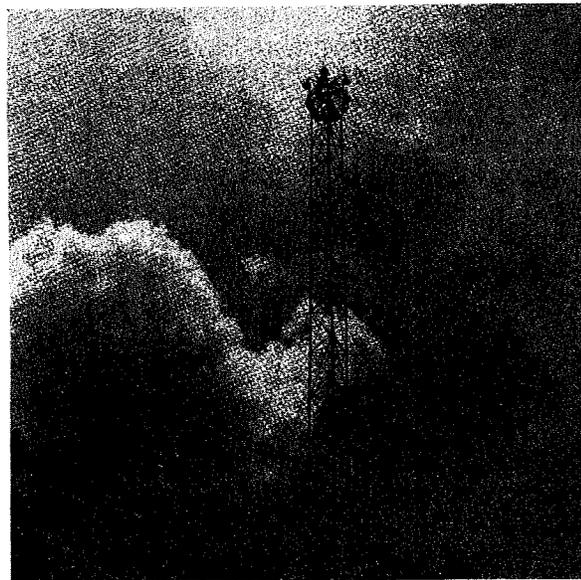
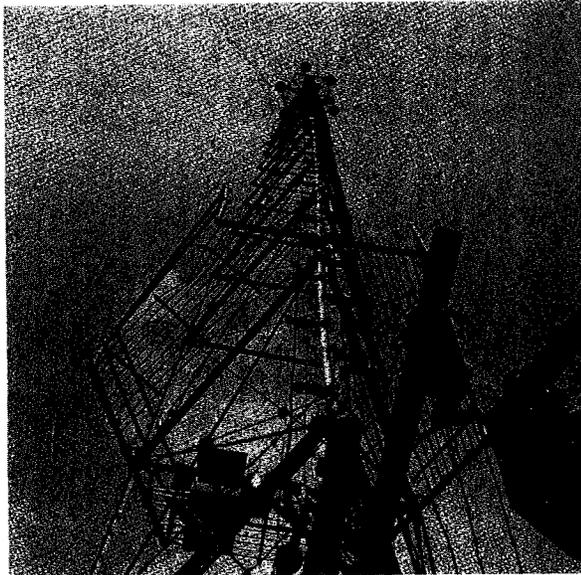


Figure 14. "Moonlight" tower lighting system.

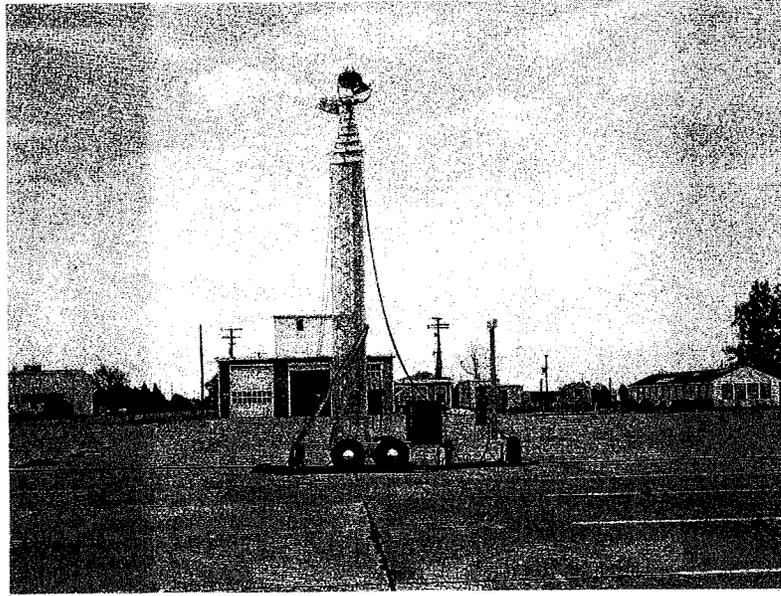
The visual cues that the motorist depends on while driving during hours of daylight are more often than not vertical relief features; i.e., curbs, medians, merging vehicles, roadway obstructions, and roadside obstructions, to name a few. Additionally, the geometric configuration of an interchange is characterized by vertical relief features as well as the horizontal plan. In other words, it is important that the driver see relief features as well as roadway surfaces. It follows that the visibility of these vertical surfaces is dependent upon the reflection of the horizontal component of light rays, normally referred to as vertical footcandles. This is in direct contrast with conventional terminology for describing illumination of the pavement expressed in horizontal footcandles, the vertical component of light that strikes a horizontal surface. Based on this concept the horizontal component of light is the basic criterion for design of interchange lighting. The vertical component (horizontal footcandles) is of secondary importance.

Facilities have been developed for mounting floodlight systems up to 150' (Figure 15). These facilities have been used in the development of experimental floodlight systems for the illumination of interchange areas.

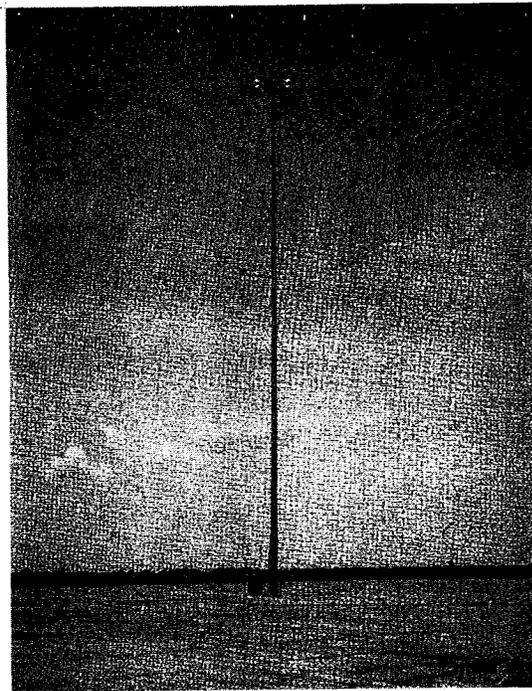
The objective in this research is to develop a system of floodlights that will produce a low level of intensity while maintaining very high uniformity of illumination. This is in direct contrast with conventional floodlighting, but it is believed sufficient to provide the visual cues to the driver as described earlier. The difficulty in this task results mainly from the fact that available floodlight units have been designed to fulfill the needs of conventional floodlighting. What is needed to accomplish this task is a floodlight that will provide a good wide uniform distribution of light without producing an excessive amount of glare which will be detrimental to the driver's visibility. Numerous floodlight units have been evaluated in the course of this research and only a limited number have been found to be satisfactory for interchange lighting purposes. As suggested previously, the requirements of such a floodlight are as follows:

1. Adequate distribution of illumination.
2. Uniformity of distribution.
3. Small reflective surface to avoid excessive glare.

The floodlight unit used in this design produced a large oblong pattern perpendicular to the direction in which it was aimed. To form the floodlight system these units were mounted at equal angular spacings so that the patterns when overlaid produced a large uniformly lighted area of approximately 1000' in diameter. Further study of this system showed that by increasing the mounting height to 150' the illuminated area was increased to a diameter of approximately 1400'.



120-FOOT TELESCOPING TOWER



150-FOOT FIXED STEEL POLE

Figure 15. High-level lighting test facilities.

This system was first tested by an experimental installation in a large interchange area in Fort Worth, Texas. Only one tower with a system of ten 1000-watt floodlights was used (Figure 16). Of course, this did not light the entire interchange area which was approximately 176 acres, but the one installation did light an area of approximately 1000' in diameter and contributed substantially to the illumination of structures and other vertical surfaces more than 1200 feet away (Figure 17). Additional studies have been conducted at the Texas A&M Research Annex and at a diamond interchange in Huntsville, Texas with similar results.

Based on the results of the high-level lighting research, various agencies have designed four lighting systems for installation; one in San Antonio, Texas, one in Texarkana, Texas, one in Rapid City, South Dakota, and one in Sioux Falls, South Dakota. All of these installations are expected to be completed in 1968. "Before and after" studies are currently being planned for one of the Texas installations.

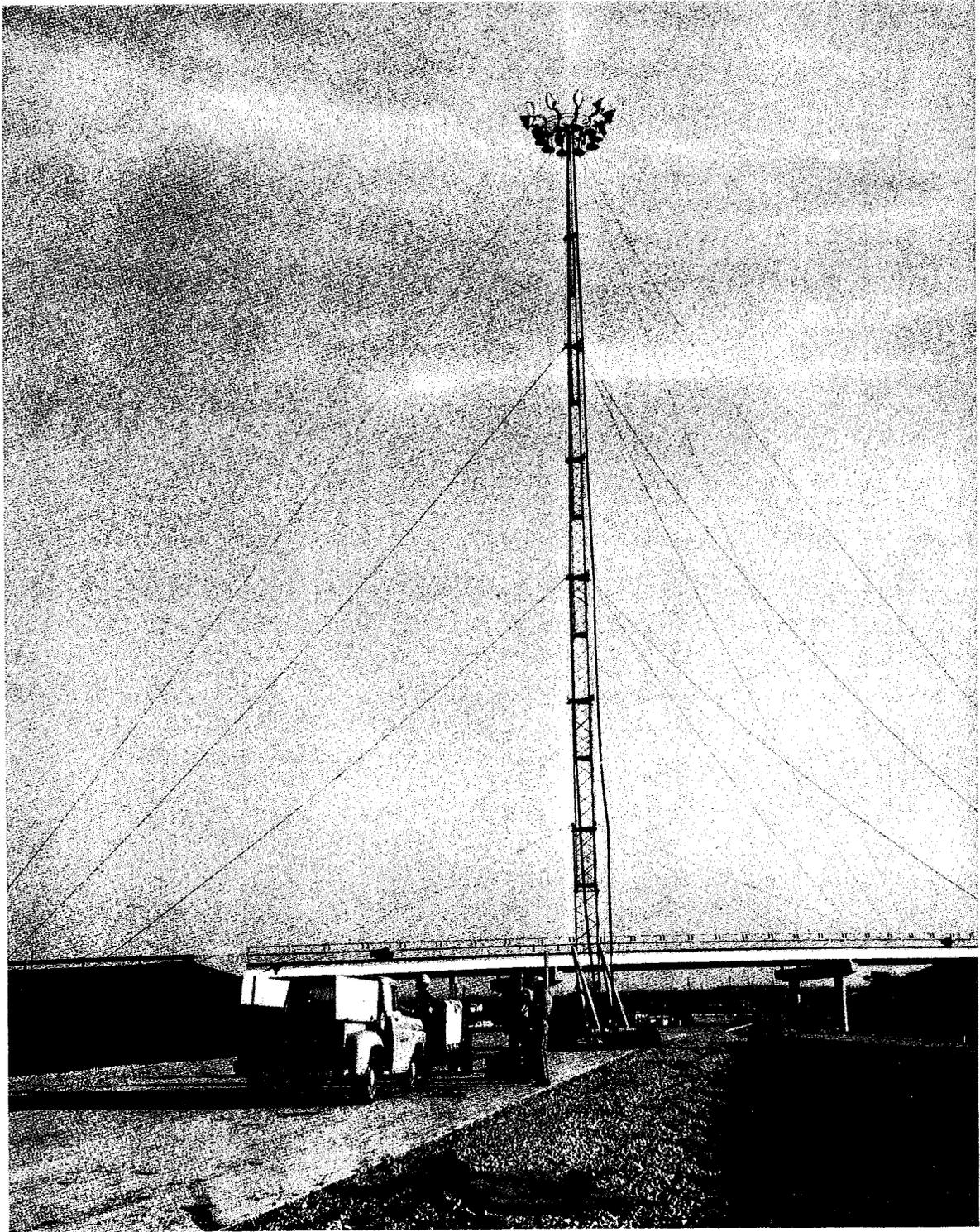


Figure 16. High-level test installation in Fort Worth.

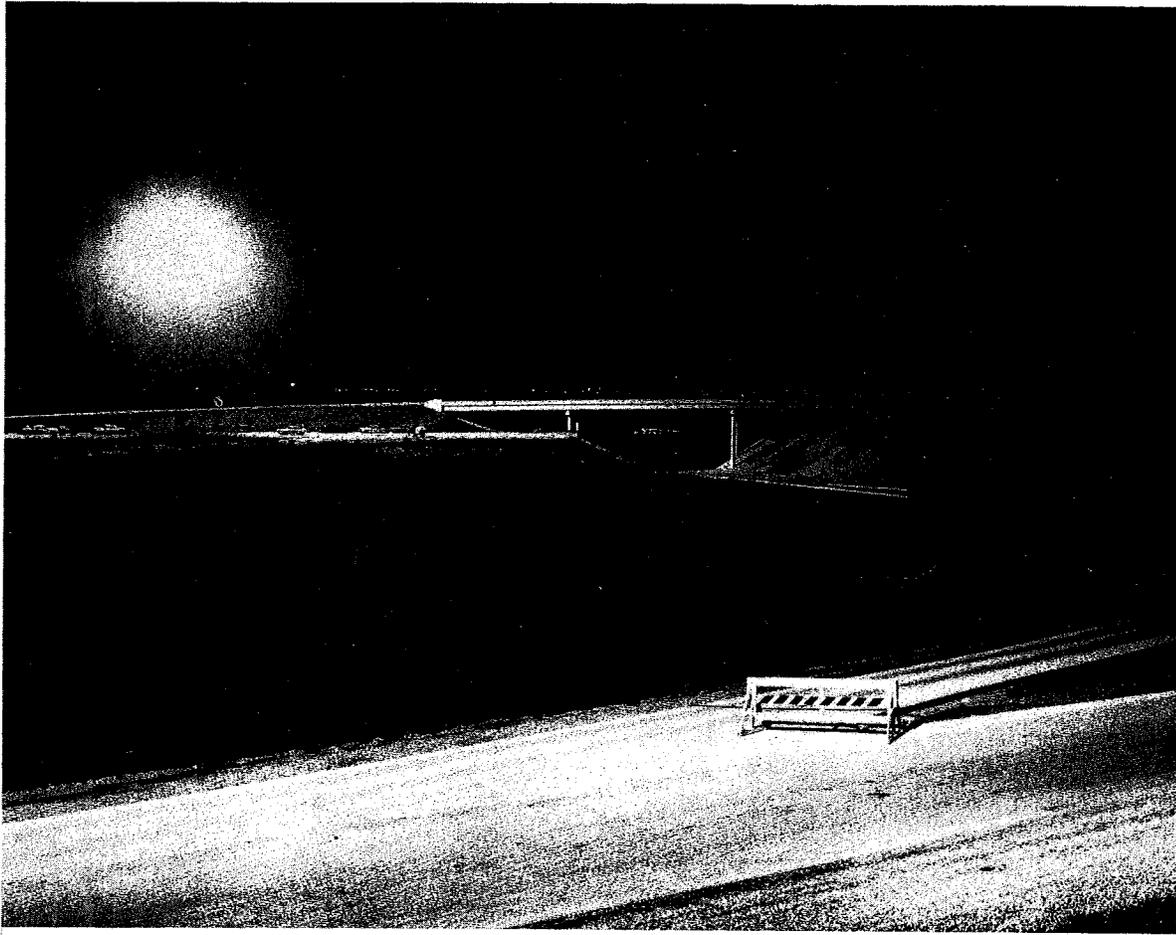
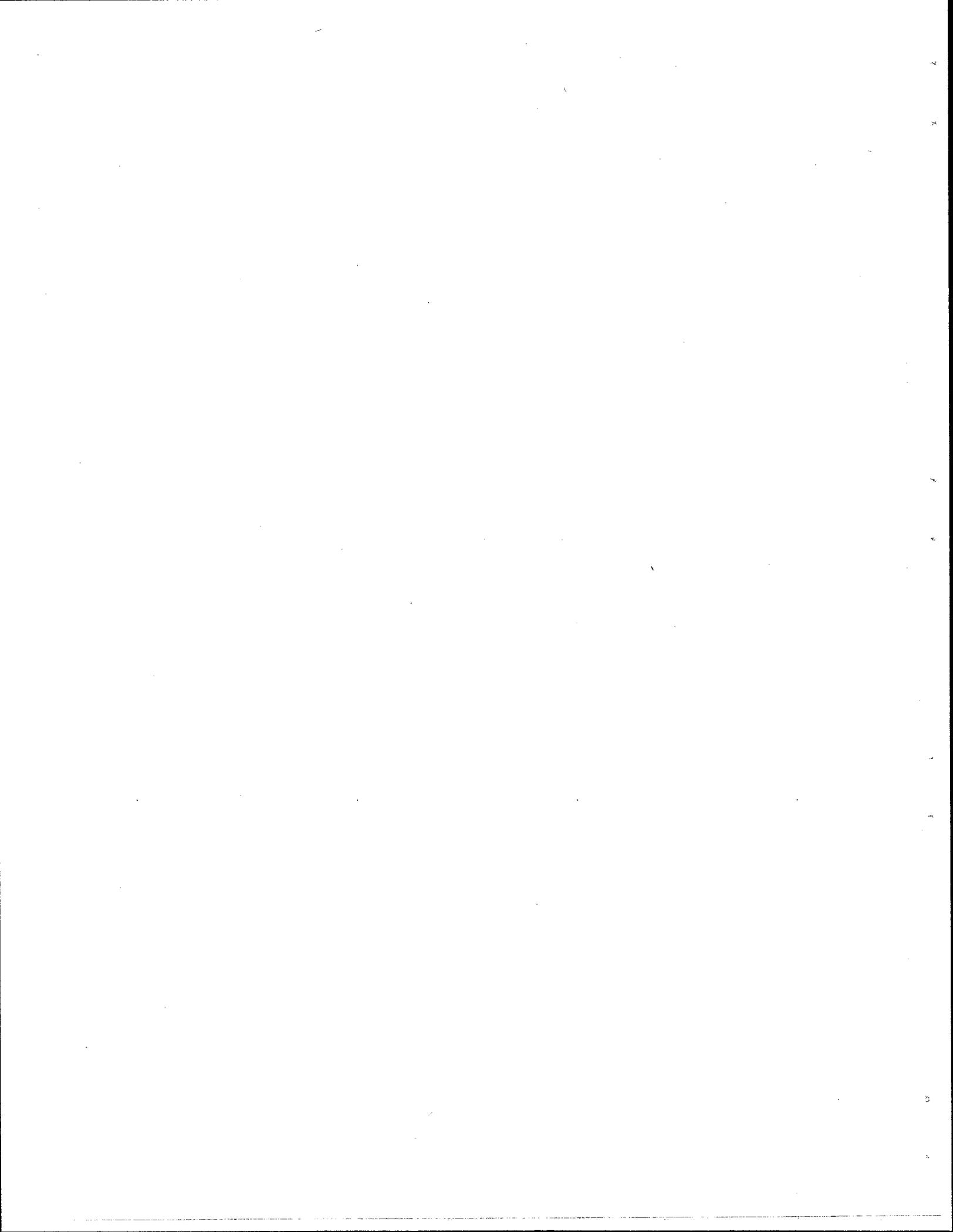


Figure 17. High-level test installation in Fort Worth.

CURRENT RESEARCH PROGRESS



CONTINUOUS LIGHTING SYSTEMS

Photometric-Visibility Relationships

Vision is the most important sensory process involved in driving. Therefore, any specification and performance criteria for roadway lighting must be directly related to the visibility conditions produced. Many attempts have been made to determine the relationships between lighting system parameters and visibility. Most of the work has been done on dynamic testing of visual acuity.³ In this approach the test object is moved and the subject views it in motion. However, any dynamic testing should require the observer to be in motion, not necessarily the object. If the observer is in motion there is the accompanying confusion in peripheral vision owing to the whole of the view apparently moving, causing cerebral confusion, both of which distinguish vision used in driving from ordinary vision. The subject in motion may be under certain stresses arising from centrifugal acceleration and deceleration forces and these may affect his visual acuity.

Currently in this research controlled field studies are being designed to determine the visibility relationships to the photometrics of lighting systems. These studies include recognition tasks by drivers in dynamic situations viewing dynamic and static objects. Each of the studies will be conducted for a series of lighting system designs and appropriate statistical procedures will be used to relate visibility to the lighting system parameters. Utilizing these data and previous studies in the research, performance criteria for continuous highway lighting systems will be developed that are sound in photometric principle and realistically related to visibility.

In addition to the above, methods of computing relative visibility and contrast for various roadway lighting systems have been investigated and employed in the research effort. Most promising of these methods is the determination of effective contrast, a relative measure of the revealing power of a lighting system. This measure (C_e) is a relationship between pavement brightness (B_p), background brightness (B_b), object brightness (B_o), and disability veiling brightness ($B_{d_{vb}}$). The measure derived from previous work by Blackwell, Pritchard and Schwab is expressed as:

$$C_e = (B_o - B_b) / (B_b + B_{d_{vb}})$$

It is significant to note that the detrimental effect of glare (disability veiling brightness) is taken into consideration in the computation of the effective contrast. This measure will also be used in rating various lighting system designs on the basis of visual revealing power.

INTERCHANGE LIGHTING

High-Level Area Lighting

In an effort to establish performance criteria for interchange area lighting continued studies of high-level installations are being made. Most recent of these was a study at a diamond interchange in Huntsville, Texas. Two 100-foot portable towers equipped with six 1000-watt floodlights each were strategically located to illuminate the points of conflict within the interchanging area. Since the interchange was previously equipped with typical safety lighting, it was possible to compare the two types of lighting.

The diagnostic research approach was used as an aid in evaluating the high-level system. This approach has long been used by the medical profession to cure ailments in the complex living body system. For the sake of explanation of the diagnostic approach, consider the procedure followed by a doctor in a routine physical examination. Through a series of clinical tests, the doctor systematically checks all of the function and response systems of the body. When a malfunction is found, he attempts to identify the illness by comparison with symptoms previously found to be associated with such illness and malfunctions. After determining the probability of existence of various illnesses or malfunctions, he selects and administers medicines which he believes will correct the disorder. The doctor carefully observes the effect of the administered remedy and in the event that expected response is not effected, he re-evaluates the probability of correct diagnosis. Changes in diagnosis are relatively frequent based on analysis of responses to remedial treatment.

In the Huntsville study the remedial treatment was pre-selected based on careful examination by the research staff. Then a diagnostic team composed of ten competent professional engineers was asked to observe the effect of the administered treatment.

The first observation was made by driving through the interchange on a pre-selected route with no illumination except vehicle headlights. The second observation was made for the existing safety lighting and the third observation was made for the two high-level towers. Based on the reported results by the diagnostic team, the safety lighting showed an improvement in rated visibility of 81 percent over no illumination. The high-level lighting showed an improvement in rated visibility of 225 percent. Improvements in comfort were rated as 76 percent and 210 percent respectively for the safety lighting and high-level lighting over no illumination.

Among the comments and notes reported by the diagnostic team, the ability to establish geometric configuration of the interchange area with high-level lighting was the most frequent. Twelve direct questions answered yes or no by the diagnostic team were reported for the three conditions studied. These twelve questions and the percen-

age answering yes or no for the three conditions are listed in Table 2. These answers revealed that the high-level lighting was superior to the other conditions. However, its shortcomings were also pointed out which will assist in the placement and design of future installations. It was concluded that the two towers could be better positioned to illuminate the exit terminal while maintaining adequate illumination at the other points of conflict. It was also concluded that the excessive glare for the high-level lighting could be reduced to that of safety lighting by lowering the face angle on the floodlights. Figures 18 and 19 are night views of the Huntsville installation.

Two high-level installations are presently being installed on the Texas Highway system. These installations are in San Antonio and Texarkana. A "before and after" study will be conducted at the San Antonio location to evaluate the effects of the high-level system on traffic operations and driver behavior. The tools being used for these studies are as follows:

1. Traffic Operation Studies
 - a. Speed Profiles
 - b. Acceleration Noise
 - c. Galvanic Skin Response
 - d. Driver Attitude

2. Photometric Studies
 - a. Intensity
 - b. Pavement Brightness
 - c. Glare (Disability Veiling Brightness)
 - d. Visibility

3. Diagnostic evaluation by a qualified professional team selected from the Texas Transportation Institute, Texas Highway Department and the Bureau of Public Roads.

In the before study, speed profiles, acceleration noise and galvanic skin response investigations have been completed.

At the completion of the before and after study and at the completion of the continued field studies at the Research Annex and elsewhere, performance criteria for high-level lighting and safety lighting will be developed and submitted to the sponsoring agency.

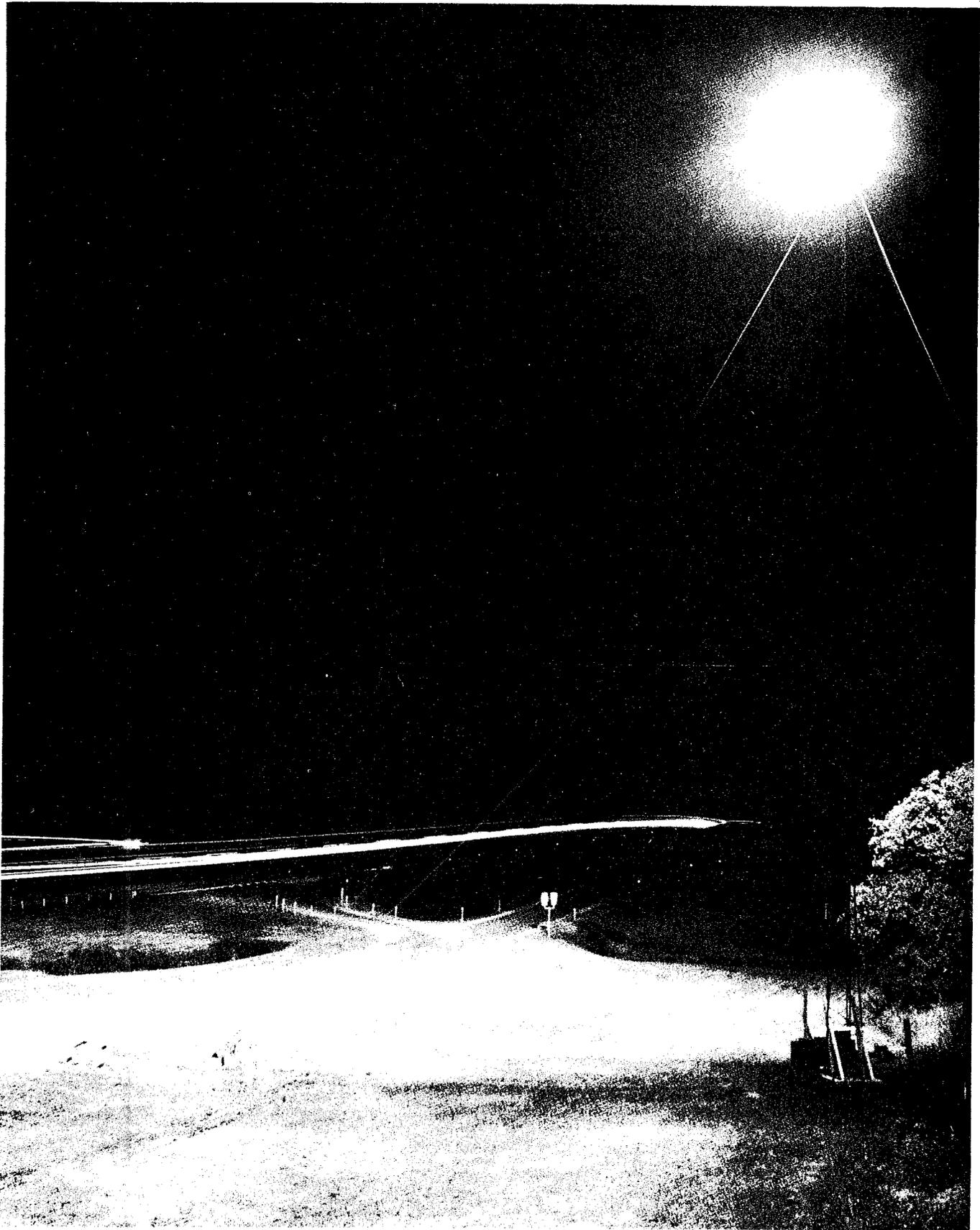


Figure 18. Night view of Huntsville installation.

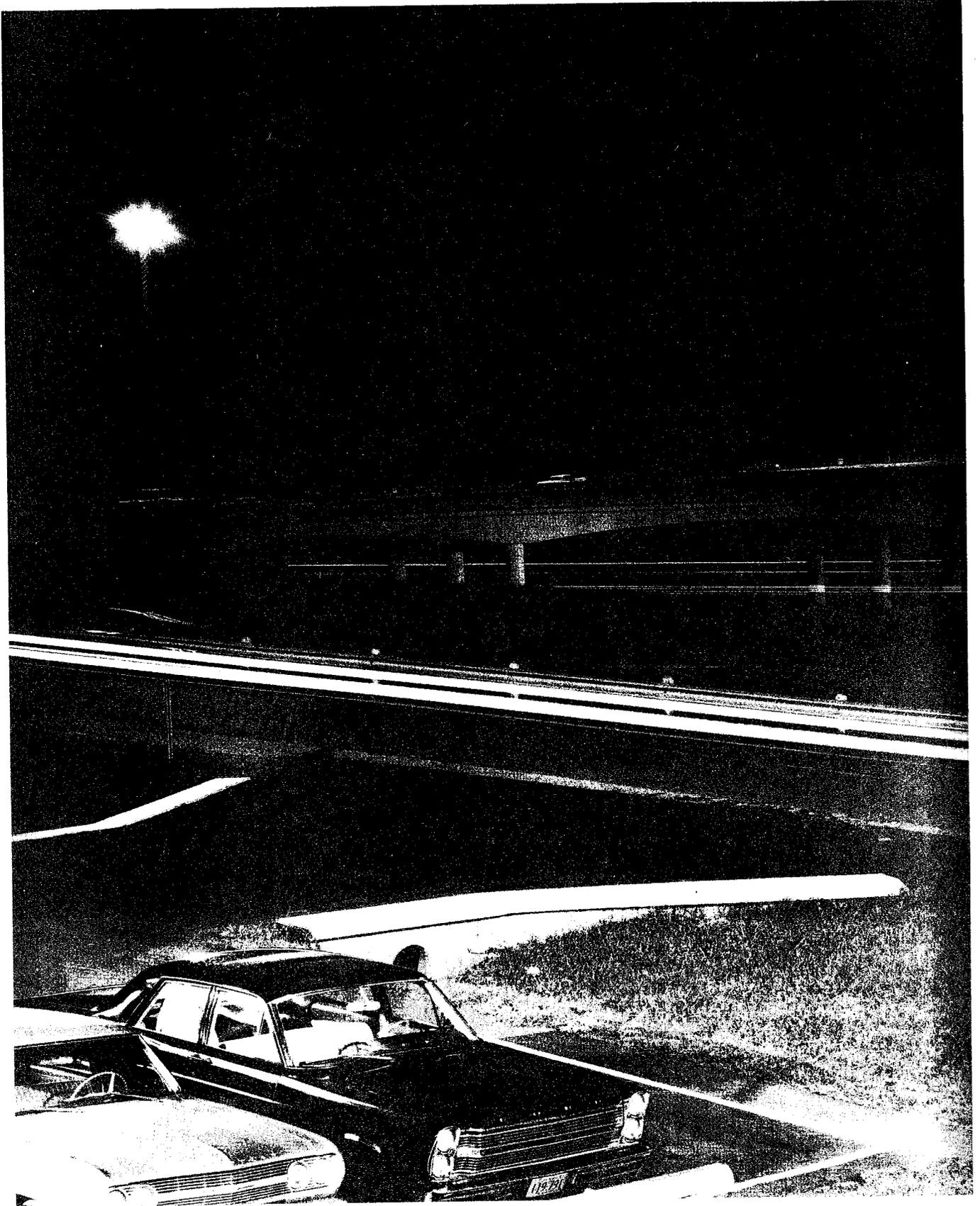


Figure 19. Huntsville installation.

Table 2

Questionnaire

DIAGNOSTIC EVALUATION STUDY

1. Can the geometric design features of the exit ramp be distinguished in time to make the required exit maneuvers safely?

No Lighting	Safety Lighting	High-Level Lighting
Yes 10% No 90%	Yes 40% No 60%	Yes 50% No 50%

2. Do you feel that additional illumination would help in distinguishing the design features earlier?

No Lighting	Safety Lighting	High-Level Lighting
Yes 100% No 0%	Yes 100% No 0%	Yes 100% No 0%

3. Did you feel comfortable in making your exit maneuvers?

No Lighting	Safety Lighting	High-Level Lighting
Yes 0% No 100%	Yes 10% No 90%	Yes 40% No 60%

4. In your opinion would additional illumination make you more comfortable?

No Lighting	Safety Lighting	High-Level Lighting
Yes 100% No 0%	Yes 90% No 10%	Yes 90% No 10%

5. Can the geometric design features of the entrance ramp be distinguished in time to make the required entrance maneuvers safely?

No Lighting	Safety Lighting	High-Level Lighting
Yes 20% No 80%	Yes 30% No 70%	Yes 100% No 0%

6. Do you feel that additional illumination would help in distinguishing the design features earlier?

No Lighting	Safety Lighting	High Level Lighting
Yes 100% No 0%	Yes 90% No 10%	Yes 20% No 80%

7. Did you feel comfortable in making your entrance maneuvers?
- | | | |
|----------------|-----------------|---------------------|
| No Lighting | Safety Lighting | High-Level Lighting |
| Yes 10% No 90% | Yes 20% No 80% | Yes 100% No 0% |
8. In your opinion would additional illumination make you more comfortable?
- | | | |
|----------------|-----------------|---------------------|
| No Lighting | Safety Lighting | High-Level Lighting |
| Yes 100% No 0% | Yes 100% No 0% | Yes 30% No 70% |
9. Were points at which you were required to stop distinguished in time to execute the stops safely and comfortably?
- | | | |
|----------------|-----------------|---------------------|
| No Lighting | Safety Lighting | High-Level Lighting |
| Yes 50% No 50% | Yes 60% No 40% | Yes 70% No 30% |
10. Would additional illumination improve the stopping conditions?
- | | | |
|----------------|-----------------|---------------------|
| No Lighting | Safety Lighting | High-Level Lighting |
| Yes 80% No 20% | Yes 60% No 40% | Yes 70% No 30% |
11. Were you hindered at any time by excessive glare? (See footnote¹)
- | | | |
|----------------|-----------------|---------------------|
| No Lighting | Safety Lighting | High-Level Lighting |
| Yes 50% No 50% | Yes 50% No 50% | Yes 60% No 40% |
12. Was the signing adequate for the conditions under which you were operating?
- | | | |
|----------------|-----------------|---------------------|
| No Lighting | Safety Lighting | High-Level Lighting |
| Yes 50% No 50% | Yes 50% No 50% | Yes 40% No 60% |

¹Comments submitted by the diagnostic team indicate that in most cases the excessive glare was due to extraneous lighting such as service station lighting, and to opposing vehicle lighting.

LIST OF REFERENCES

1. Cleveland, Donald E., "Intersection and Sign Illumination for Highway Safety and Efficiency," Research Report 5-9 (Final), Texas Transportation Institute, August, 1966.
2. Rowan, Neilon J., and Walton, Ned E., "Photometric Studies of the Austin Moonlight Tower Lighting Systems," Research Report 75-4, Texas Transportation Institute, October, 1966.
3. Mullin, E. F., "The Part Visibility Could Play in Road Design," Journal of the Australian Road Research Board, Vol. 2, No. 9, September, 1966.
4. Blackwell, H. R., Schwab, R. N., and Pritchard, B. S., "Illumination Variables in Visual Tasks of Drivers," Public Roads, Vol. 33, No. 11, December, 1965.