HIGH-MAST LIGHTING

by

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Research Report Number 75-12

Supplementary Studies in Highway Illumination

Research Study Number 2-8-64-75

Sponsored by the
Texas Highway Department
in Cooperation with the
U. S. Department of Transportation
Federal Highway Administration

February, 1969

TEXAS TRANSPORTATION INSTITUTE
Texas A&M University
College Station, Texas

DISCLAIMER

The opinions, findings and conclusions expressed in this public are those of the authors and not necessarily those of the Federal Hi Administration.

PREFACE

This interim report discusses the findings of research in interchange area lighting as a part of Research Study 2-8-64-75. This research was conducted by the Texas Transportation Institute in cooperation with the Texas Highway Department and the U. S. Department of Transportation, Federal Highway Administration.

The findings of this research have been implemented by the Texas Highway Department in the design and construction of several installations of high-mast area lighting. However, the research is not complete and is being continued under Research Study 2-8-69-137.

The various phases of the research in Study 2-8-64-75 have been covered in detail in eleven 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," Ned E. Walton and Neilon J. Rowan, 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.

ABSTRACT

Research Report 75-12 contains the documentation of research on high-mast lighting by the Texas Transportation Institute. The concept of high-mast lighting is discussed and the objectives of the research listed. The report indicates that high-mast lighting can be effective and economical, especially in interchange areas. Details of the development of proto-type and field installations are included. Recommendations for implementation have been made and include a suggested design procedure.

SUMMARY

High-Mast Lighting is a term coined to describe the application of the area lighting concept to highway interchanges and complex intersections. Although high-mast lighting is recognized as a "popular new concept," it is the application rather than the concept that is new. The concept dates back to the 1800's when tall masts were installed in several cities to illuminate large areas and thus provide a pleasant nighttime environment.

The first known application of high-mast lighting to highways was the Heerdter Triangle installation in Dusseldorf, Germany, in the late 1950's. It was followed by installations in other European countries, including Holland, France, Italy and Great Britain. These installations stimulated interest within the Texas Highway Department to consider similar applications.

The principal task in applying high-mast lighting to highway interchanges is to synthesize the visual advantage provided the driver by daylight. This visual advantage consists of being able to see all things pertinent to the driver decision-making process well in advance so that he may assimilate the information, plan his maneuvers and execute them in an orderly fashion. Among other things, it requires that he be able to distinguish roadway geometry, obstruction, terrain, and other roadways, each in its proper perspective.

In order that high-mast lighting may accomplish the principal task as described above, the system must provide:

1. Adequate illumination to reveal the roadway geometry;
2. Adequate illumination for visibility of objects within the roadway;
3. Adequate illumination on areas other than roadways for proper orientation, perspective, and speed and distance judgment;
4. Good uniformity of illumination and brightness, especially on roadways; and
5. Minimum discomfort and disability glare.

The objectives of the research on high-mast lighting were:

1. To determine the desirability of lighting interchanges with high-mast lighting;
2. To develop a system of light sources, supporting hardware, and design procedures for lighting interchanges with high-mast lighting;
3. To test the prototype system through application under actual operating conditions; and
4. To recommend guidelines for design of high-mast lighting based on observations of test installations.

The research was strongly oriented toward applications. Time, funding and specialized technical competence did not permit an exhaustive laboratory and theoretical investigation of all the underlying ramifications of lighting, visibility, physiological and psychological aspects of the problem. Rather, a subjective approach was taken most frequently in the evaluation, utilizing supporting technical data on light distributions and glare effects.

Prototype systems of the concept were developed and tested at several locations. Based on the satisfactory results of the preliminary tests, two full-scale installations were made at two interchanges in Texarkana and San Antonio to facilitate further study.

Diagnostic studies of the two full-scale installations revealed that high-mast lighting is definitely superior to other types of lighting for interchange areas. The studies also revealed that high-mast lighting compares very favorably with conventional techniques of lighting continuous roadway sections.

Research is continuing on high-mast lighting to improve on the development and application of the concept. However, information is presently available that will allow the designer to implement high-mast lighting to achieve very acceptable lighting installations.

Photometric parameters that appear to yield most satisfactory results are as follows:

1. Average illumination - .50 horizontal footcandles on the roadway. Smaller intensities are acceptable for areas other than the roadway.

2. Uniformity of illumination - average-to-minimum ratios of 2 to 1 and maximum-to-minimum ratios of 4 to 1, both of which control also the uniformity of brightness to an acceptable level.

Supports for the illumination assemblies should be placed as far from the roadway as is possible to reduce maximum intensities and to reduce glare and collision hazards while maintaining adequate illumination on the roadways.

Hardware for the support assemblies can be framework towers or poles equipped with steps for climbing, or raising and lower mechanisms for the illumination assemblies.

Although most experienced lighting designers have their own established design procedure which should be adaptable to the design of high-mast lighting, the research staff has recommended a procedure for those requiring one.

IMPLEMENTATION STATEMENT

Although research is continuing on high-mast lighting under Research Study 2-8-69-137, sufficient information is presently available to allow implementation. The findings of the research contained in this study indicate that high-mast lighting can be used as a new tool to solve many interchange lighting problems.

A section is included in this report on Recommendations for Implementation. In addition to the recommendations, a suggested design procedure is included as Appendix B. Although the recommendations and design procedure are not the only means to obtain suitable implementation, the research agency is of the opinion that they open the door to new and better techniques for the future.

This research has shown that high-mast lighting can be expected to provide savings in time and money, increased safety, and last, but certainly not least, tremendous improvements in interchange aesthetics.

Several installations of high-mast lighting have been completed at the time of this printing. A partial listing of these installations follows and includes the use of poles, towers, floodlights, and IES Type V distributions.

- Texarkana, Tex-Ark. - 100'-150', floodlights, framework towers
- San Antonio, Tex. - 100', floodlights, framework towers
- Canyon, Tex. - 150', floodlights, poles with hoisting devices
- Dallas, Tex. - 150', floodlights, poles with hoisting devices (two installations)
- Wichita Falls, Tex. - 150', floodlights, poles with hoisting devices

- Corpus Christi, Tex. - 150', floodlights, poles with hoisting devices
- Waco, Tex. - 150', floodlights, poles with hoisting devices
- Rapid City, S.D. - 100'-120', floodlights, framework towers
- Sioux Falls, S.D. - 100', floodlights, framework towers
- Omaha, Neb. - 150', floodlights, poles with hoisting devices
- North Platte, Neb. - 150', IES Type V, poles with hoisting devices
- Jamestown, N.D. - 150', floodlights, framework towers
- Grand Forks, N.D. - 150', floodlights, framework towers
- Seattle, Wash. - 100', IES Type V, poles with steps, poles with climbing car (two installations)

Several others, in addition to the above, have been installed or, are in the design stage. Similar applications have also been noted in shopping centers and parking areas.

A recent survey indicated that high-mast lighting has been used quite widely by at least ten state highway departments and is planned for use by an additional ten states and nine municipalities.

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INTRODUCTION

High-Mast Lighting is a term coined to describe the application of the area lighting concept to highway interchanges and complex intersections. Although high-mast lighting is recognized as a "popular new concept", it is the application rather than the concept that is new. The concept dates back to the 1800's when tall masts were installed in several cities, including Philadelphia and Vancouver, to illuminate large areas and thus provide a pleasant nighttime environment. The operation and maintenance of these installations proved very costly and most were abandoned. However one of these systems is still in use today. About the turn of the century, the city of Austin, Texas, traded a narrow-gage railroad for a number of 150-foot towers and installed them at several points throughout the city where artificial "moonlight" was desired. Although the light sources have been changed with advancements in technology, most of the towers are still used effectively.

The first known application of high-mast lighting to highways was the Heerdter Triangle installation in Dusseldorf, Germany, in the late 1950's. It was followed by installations in other European countries, including Holland, France, Italy, and Great Britain.

Interest in high-mast lighting in this country was stimulated by the successful applications in Europe, and the increasing difficulty of lighting some highway interchanges by conventional methods. The Texas Highway Department requested that an investigation of high-mast lighting applications be made within Research Study 2-8-64-75, a roadway lighting research study already under way at TTI.

On the basis of various field observations of high-mast lighting in connection with the Research Study, two trial installations were made in Texarkana, and San Antonio, Texas. Almost simultaneously, an installation was made at an interchange near Seattle, Washington. The Washington installation utilized IES Type V prototype luminaires with a circular light distribution, whereas, the installations in Texas utilized a system of floodlights on each mast. Studies of the Texas installations and a discussion of the two types of systems are included in later sections of this report.

THE HIGH-MAST LIGHTING CONCEPT AND OBJECTIVES

The principal objective in applying high-mast lighting to highway interchanges is to synthesize the visual advantage provided the driver by daylight. This visual advantage consists of being able to see all things pertinent to the driver decision-making process well in advance so that he may assimilate the information, plan his maneuvers and execute them in an orderly fashion. Among other things, it requires that he be able to distinguish roadway geometry, obstructions, terrain and other roadways, each in its proper perspective.

In order that high-mast lighting may accomplish the principal objective as described above, the system must provide:

1. Adequate illumination to reveal the roadway geometry;
2. Adequate illumination for visibility of objects within the roadway;
3. Adequate illumination on areas other than roadways for proper orientation, perspective, and speed and distance judgement;
4. Good uniformity of illumination and brightness, especially on roadways; and
5. Minimum discomfort and disability glare.

Adequate Illumination to Reveal Roadway Geometry

The most important communication element of the highway system is the roadway itself (1). It is the view of the road that gives the driver direction and visual contact with the system. For slow to moderate operating speeds and few major decisions, vehicle headlights adequately illuminate the roadway and provide direction and visual contact. At high speeds, and particularly in complex driving situations, headlights are not adequate to provide the necessary visual contact with the roadway. Therefore, to satisfy this requirement, fixed lighting that will illuminate the roadway a safe distance ahead is needed. Virtually any type of fixed lighting, when properly designed, can satisfy this requirement.

Adequate Illumination for Visibility of Objects within the Roadway

This requirement cannot be defined fully because the technology and conditions related to seeing objects have not been defined. First, the type and nature of the object to be seen are highly variable depending on the type of facility. Some feel that silhouette seeing is most prevalent, and thus a bright pavement will provide brightness contrast between the object and pavement. On the other hand, most objects that pose a significant hazard to the driver have predominant vertical surfaces, and therefore a significant horizontal light component will normally provide object brightness in contrast with the pavement. Therefore, it seems logical that there should be a balance of horizontal and vertical components of light in the illuminated area with due regard to the effects of glare. Conventional lighting systems seem to accomplish this very well, and therefore the restrictions that apply to roadway luminaires should apply to high-mast lighting.

Adequate Illumination on Areas Other than Roadway

If a lighting system is to synthesize the visual advantage of daylight, adequate illumination must cover the entire visual field of the driver. The geometric configuration of an interchange is characterized by vertical relief features as well as the horizontal plan.

It follows that the visibility of these surfaces is dependent upon the horizontal component of light rays, normally referred to as vertical footcandles. Therefore, to meet this requirement, the lighting system must provide a balance between the horizontal and vertical components of light.

Good Uniformity of Illumination and Brightness

Uniformity of illumination on the roadway surface is usually a desirable characteristic of a roadway lighting system (2). It provides a more comfortable environment by reducing fatigue and nervous irritation normally accompanying large and frequent changes in the distribution of illumination. There are arguments pro and con on uniformity of illumination, and either can be correct, depending on the existing conditions. Uniformity is not desirable when the background and the object to be seen both have the same brightness or contrast characteristics. On the other hand, uniformity contributes to the visibility of objects when the objects have greater reflectance characteristics than the background, a condition which is predominant regarding objects on the roadway.

The benefits of uniformity of illumination are best illustrated considering the situation of an individual looking into a relatively dark area from a brightly lighted area. The individual's ability to see objects in the dark area can be improved in two ways: 1) increasing the overall intensity, that is, the light intensity in both areas until the relative effect of differentials in light intensity is minimized (the eye cannot detect differences in intensities above about 4 to 8 ft.c.); and 2) changing the distribution of light by reducing the intensity of light in the area occupied by the viewer and increasing the intensity of the area viewed (3).

It is this latter concept that justifies and substantiates the use of lower light intensities in lighting systems where greater uniformity can be achieved. Also, this is supportive evidence for the use of the maximum-to-minimum ratio as well as the average-to-minimum ratio to describe uniformity.

Minimum Discomfort and Disability Glare

There are as many theories as there are theoreticians on the effects of glare from roadway lighting systems. There are those that claim disability glare is the most important consideration (4), while others claim that once you have taken care of discomfort glare, disability glare ceases to be a problem (5). The latter theory seems to be most prevalent in Europe where glare is given much greater consideration and the acceptable threshold is much lower than in the United States.

Earlier research on this project (6) showed that mounting the light sources higher and spacing them farther apart reduced the glare effects. In high-mast lighting, there is the additional benefit of being able to place the light source away from the roadway and out of the direct view of the driver.

It is recognized that controlling the vertical angle of candlepower is the most effective means of controlling glare, and consideration should be given to recommendations set forth in ASA Standards for semi-cutoff type distribution.

Research Objectives

The objectives of the research on high-mast lighting were:

1) To determine the desirability of lighting interchanges with high-mast lighting;

2) to develop a system of light sources, supporting hardware, and design procedures for lighting interchanges with high-mast lighting;

3) to test the prototype system through application under actual operating conditions; and

4) to recommend guidelines for design of high-mast lighting based on observations of test installations.

It should be recognized that this research was strongly oriented toward applications. Time, funding and specialized technical competence did not permit an exhaustive laboratory and theoretical investigation of all the underlying ramifications of lighting, visibility, physiological and psychological aspects of the problem. Rather, a subjective approach was taken most frequently in the evaluation, utilizing supporting technical data on light distributions and glare effects. This seems justified when specialized technology has not yet been able to develop measurement techniques and apparatus to accurately measure the relationships of illumination and visibility.

Galvanic Skin Response measurements and subject driver speed profiles were made at the installations in Texas, but the results were inconclusive.

RESEARCH AND DEVELOPMENT OF HIGH-MAST LIGHTING

As mentioned earlier, the apparent success of high-mast lighting installations in Europe coupled with difficulties in adequately lighting complex interchanges with conventional methods stimulated the thinking of the Texas Highway Department regarding the desirability of high-mast lighting as a technique of interchange lighting. The effectiveness of the Austin "moonlight" towers was an added incentive, and preliminary efforts of this study were made with the Austin towers, replacing the six 400-watt mercury vapor lamps used in the towers with six 1000-watt mercury lamps for test and observation. The results of this preliminary study are reported in Research Report 75-4 (7).

This study demonstrated favorable effects of high-mast lighting using large light sources, but it also indicated the need to provide better control of the distribution of light, since the Austin towers were equipped with old radial type reflectors that provided virtually no beam control. Thus, it was decided to obtain a portable high-mast support device and test various light sources and fixtures for application in high-mast lighting.

A portable antenna tower, capable of 100-foot mounting heights, was purchased and modified for high-mast lighting. Also, a grid system was established at the Texas A&M Research Annex Outdoor Lighting facility to facilitate measurement of light distribution.

Many floodlights were obtained from various manufacturers for testing, and measurements and observations of light distribution were made for each floodlight, singly and in combination with other floodlights to form a system. From these observations it was found that most floodlights did not satisfy the requirements previously discussed. Most floodlights had been designed for lighting areas to a relatively high intensity, and were not capable of providing a low, even distribution of light.

One particular floodlight, because of the unique reflector design, did provide a rather low intensity, uniform distribution when fitted with a clear mercury vapor lamp. This distribution is characterized by a low vertical cut-off and a relatively high lateral cut-off, giving a long elliptical distribution with the long axis perpendicular to a radial from the base of the support. By placing multiples of the floodlights in a system, the elliptical distributions were overlapped, producing a large, uniformly lighted area. By using ten of these floodlights at 36-degree angular spacings and adjusting them to an angle of 45° measured from the support, an effective distribution of light was achieved, as illustrated in Figure 1.

Prototype Studies

With the prototype system described above, observations were to be made in an actual interchange area to determine the effectiveness of the lighting system in relation to the various interchange elements. A partially completed interchange (I-35W and I-820 in Fort Worth) was selected for the study. The 100-foot tower was erected in close proximity to a three-level structure within the interchange. The floodlights were adjusted to provide the distribution shown in Figure 1. Sample light intensity measurements were made to check the distribution against that previously achieved at the research facility.

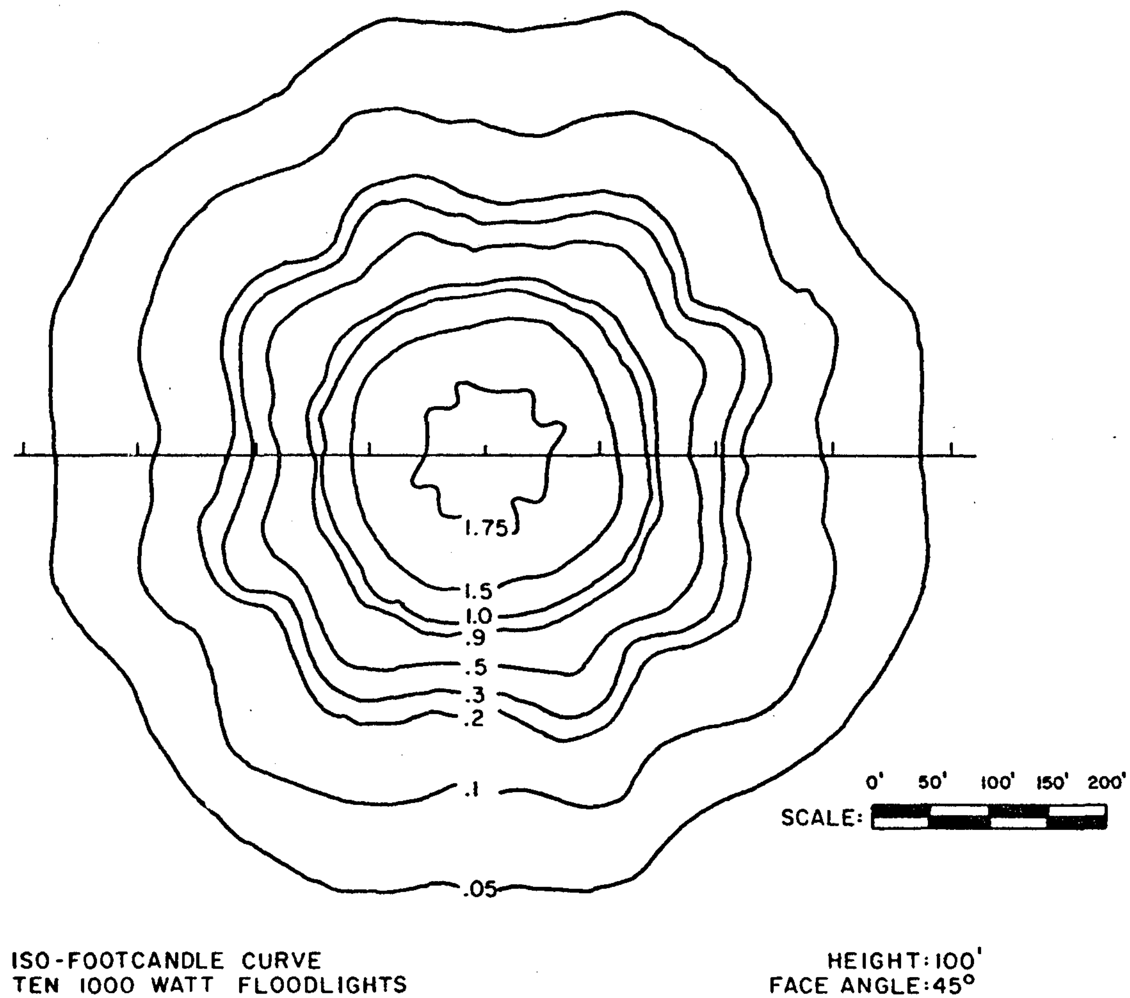

1.75
1.5
1.0
.9
.5
.3
.2
.1
.05
0' 50' 100' 150' 200'
SCALE:
ISO-FOOTCANDLE CURVE
TEN 1000 WATT FLOODLIGHTS
HEIGHT:100'
FACE ANGLE:45°

FIGURE 1

On two consecutive nights, observations were made by approximately 40 representatives of various governmental agencies, many from other states. The group was nearly unanimous in its approval of the lighting concept. The observations of the group and the research staff can be summarized as follows:

1. The system lighted an area of about 1000 feet in diameter to a sufficient level that interchange features were visible.
2. The use of area lighting of interchanges is highly beneficial from the driver information and orientation viewpoint. Lighting grass areas as well as the roadway provided the observer with orientation information relating to general road geometry. Vertical surfaces up to 1200 feet away were illuminated sufficiently to provide general information cues, demonstrating the value of a significant horizontal component of light in interchange lighting.
3. High-mast lighting reduces the adverse effects of mounting height of luminaires relative to multi-level interchanges. The mounting height of luminaires is a very critical problem in lighting interchange structures, particularly three- and four-level structures. Attempts to light lower structures frequently put luminaires very close to the driver's eye level on upper structures. High-mast lighting reduces this effect due to the fact that differences in structure levels are insignificant compared to the mounting height.

A second field study was conducted at a diamond interchange on I-45 in Huntsville, Texas, using two 100-foot towers, each equipped with ten floodlights. These towers were located 1400 feet apart in the two areas between the entrance ramps and the freeway lanes. This high-mast system was evaluated in comparison to a conventional "safety lighting" system consisting of 400-watt sources at 30-foot mounting heights, located at points of conflict.

The effectiveness of each of the systems and a comparison of the two were made by a team of observers composed of professional people representing several disciplines of the highway industry. The team judged the conventional "safety lighting" system to be inadequate, even for the comparative simplicity of the diamond interchange under study.

Regarding the high-mast system, the team felt that lighting of the entrance areas and the main lanes between the two towers was adequate, but lighting in the exit areas was inadequate. This inadequacy was further complicated by the existence of commercial development lighting near one exit ramp connection to the frontage road. It was obvious that the designer must recognize the effects of extraneous or developmental lighting on the effectiveness of interchange lighting. Additionally, it was recognized that light sources should be located so that the greater amount of light should be concentrated on exit areas to provide increased recognition of these areas.

On the basis of the studies at Fort Worth and Huntsville, the Texas Highway Department felt that high-mast lighting provided the solution to many interchange lighting problems. Additional study of the concept was needed to provide data for design.

On the basis of the two previous studies where only parts of the interchange were lighted, it was recognized that a completely lighted interchange was needed to facilitate a realistic evaluation. Such a study could be provided in one of two ways

1. Procure additional portable lighting equipment to completely light an interchange, or
2. Design a permanent high-mast lighting system on the basis of additional photometric studies and the limited field studies.

It was felt that the latter approach would make better use of funds available because the lighting system would serve the public as well as provide facilities for research. Two installations were planned, one at a small cloverleaf interchange on I-30 near Texarkana, and one at a complex cloverleaf-directional combination on I-10 in San Antonio.

Additional studies of lighting systems were conducted at the Field Laboratory at the Texas A&M Research Annex. A 100-foot steel shaft was erected as a prototype assembly for future field use. Mounting gear for floodlights was designed so that the floodlights could be lowered for servicing. This mast was used with the portable tower to facilitate a study of mast spacings. The steel mast was later modified to provide a mounting height of 150 feet. A new floodlight ring assembly with a locking device and electrical contacts was installed. This new equipment provided field experience for future design work, and permitted collection of photometric data for mounting heights up to 150 feet. An iso-footcandle curve for ten 1000 watt floodlights (mercury vapor lamps) mounted at 150 feet and aimed at 45° with the vertical is shown in Figure 2.

Texarkana Study

The installation of high-mast lighting at the I-30 - US-59 interchange near Texarkana consisted of one 150-foot tower with 10 1000-watt

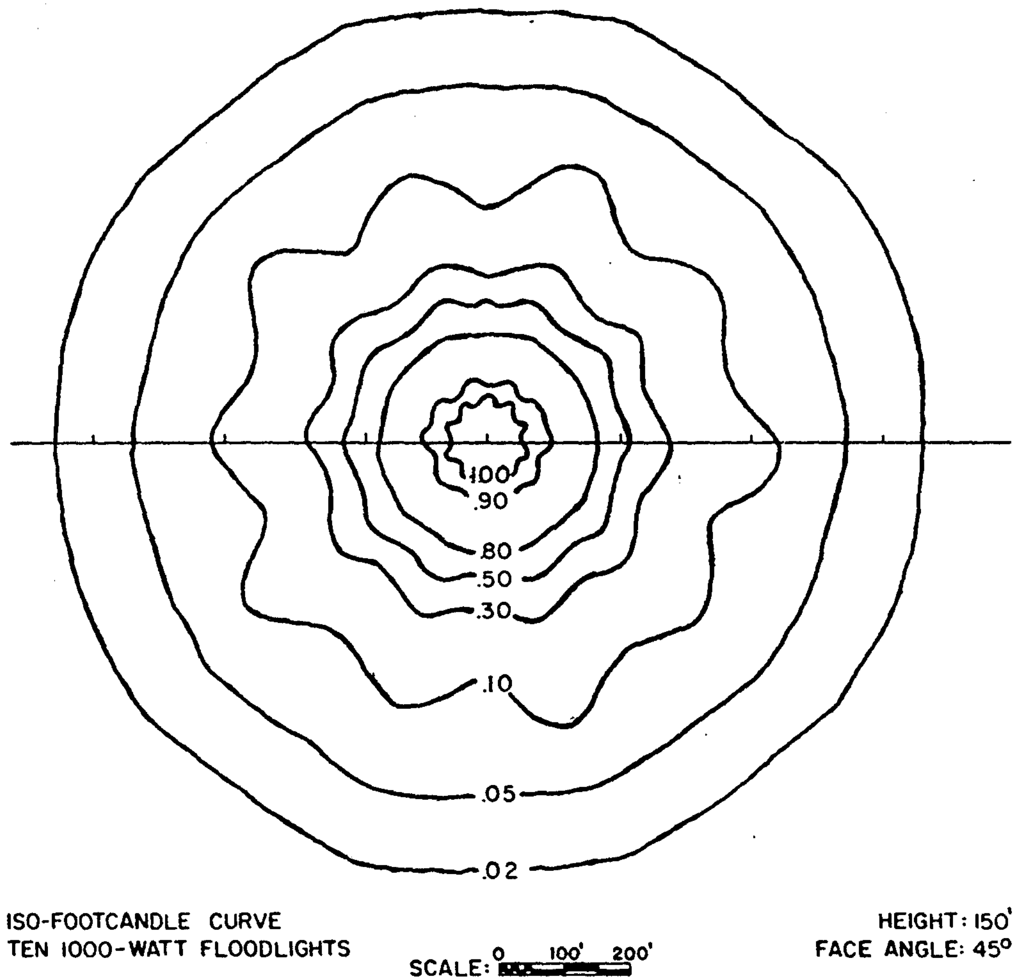

.100
.90
.80
.50
.30
.10
.05
.02
ISO-FOOTCANDLE CURVE
TEN 1000-WATT FLOODLIGHTS
SCALE: 0 100' 200'
HEIGHT: 150'
FACE ANGLE: 45°

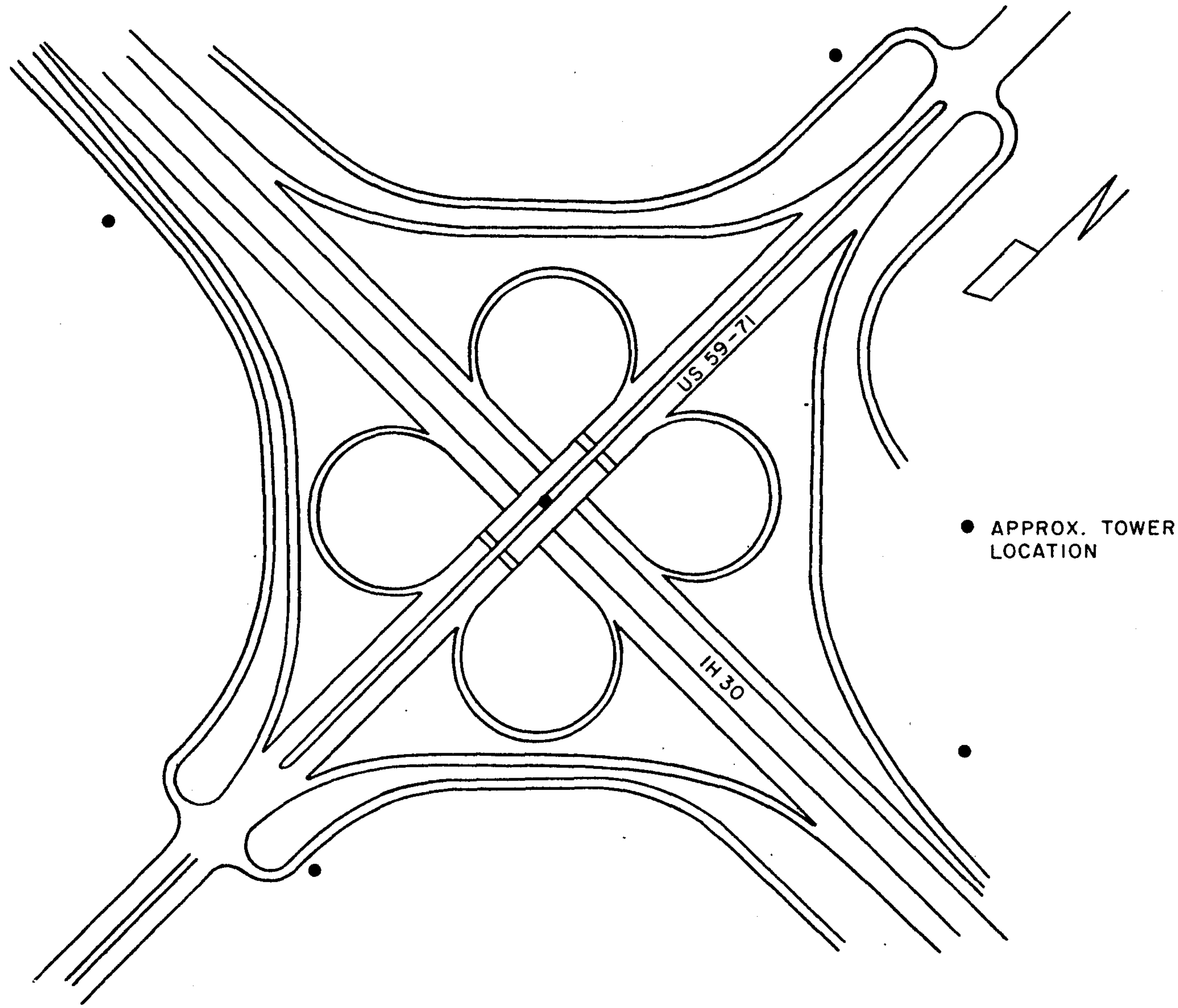
FIGURE 2

floodlight, and four 100-foot tower each equipped with six 1000-watt floodlights to light one quadrant of the interchange (Figure 3).

The research staff conducted on an on-site study of the lighting system. Light intensity measurements were made after the system had been in operation 6 months. These results are shown in Table 1. There results represent intensities and uniformities slightly below that desired. Also, speed profiles of subject drivers in an instrumented vehicle were recorded before and after the installation of lighting.

A subjective-type diagnostic study was conducted to determine the effectiveness of the installation in relation to night visibility, driver comfort and safety. The study area consisted of the light interchange and the area between two diamond interchanges on I-30 to the west and east. A test route was chosen to require all typical maneuvers through the interchange, including straight through, left turn onto freeway, right turn from freeway, right turn onto freeway and left turn from freeway.

The study was performed in two parts; the first under "lights-off" conditions, with no illumination except vehicle headlights, and the second under "lights-on" conditions, with the five towers and vehicle headlights in operation. Twelve engineers of the Texas Highway Department took part in the study. Each observer drove the test route under the two conditions and then completed a questionnaire. Questions were related to visibility of the roadway features, including lane markings, on- and off-ramp tapers, ramp terminals, signs, sight distances for stopping and seeing small objects on the pavement, recognition of decision points, uniformity and level of illumination and brightness, glare, and visual discomfort.



Texarkana High-Mast Installation

FIGURE 3

TABLE 1

TEXARKANA PHOTOMETRICS

SECTION	AVERAGE INTENSITY HOR. FT-CD	AVG./MIN RATIO
I-30 Westbound	.27	3.4/1.0
I-30 Eastbound	.34	2.1/1.0
US59 Southbound	.28	2.8/1.0
US59 Northbound	.28	2.8/1.0
NW Outer Loop	.25	4.0/1.0
SE Inner Loop	.57	3.3/1.0
N.W. Quadrant*	.22	-
S.W. Quadrant	.33	-
N.E. Quadrant	.30	-
S.E. Quadrant	.21	-

*Each quadrant includes all areas from 50 feet outside the outer loop to the center lines of the two crossing roadways. Measurements made on 50-foot grid intervals.

The questionnaire showed that a large majority of the observers approved he hiσh-mast lighting. Under "lights-on" conditions, the subjects felt they ... provided with increased visibility and sight distance, and able to distinguish geometric features of the interchange in time to t in a rational manner. Highway signs were easier to read and decision ts such as exit and entrance ramps more easily recognized. Drivers cated thay were able to better judge the relative positions of their cle on the interchange, and merge more easily into the traffic stream. e was aggreement that the interchange was fairly uniformly illuminated ng the driver an overall picture of the area in which to make his uver. Observers could recognize the type of interchange and make ing judgements accordingly.

In the "lights-off" study the majority of observers agreed that additional mination would help improve visibility, driver comfort, and their ity to recognize geometric features and decision points. The comments established that a driver who can see the entire exit ramp, rather than a relatively short distance ahead of his vehicle, is better able to e his required maneuvers. In addition, during a merging operation, iver who is aware of the entrance configuration and is able to see the way upstream of the merge, can confidently increase his merging speed better judge the critical gap in the traffic stream.

In the "lights-on" study some drivers expressed uncertainty as to her additional illumination would impro[illegible] er, several spots were apparent in the interchange area and it was concluded that five towers were placed too f[illegible] to give the best results.

One serious defect of the design was revealed by the study, concerning the placement of the four towers on each of the approach legs. In all cases these towers were in the direct line of sight of drivers using the outer connecting ramps in adjacent quadrants to the towers. In these cases glare from the towers was indicated as a minor problem. Two solutions were suggested: (1) more careful placement of supports and, (2) reduced aiming angle of the floodlights (which in some cases was as high as 60 degrees).

To summarize the findings of the study, emphasis is given to the changes that can be made in future design to improve the effectiveness of the system. Future design should use closer spacings of masts to (1) provide more illumination in all areas and greater uniformity, (2) allow lower aiming angles of individual floodlights to reduce the glare effects, and (3) allow more strategic placement of masts to further reduce the glare effects. It should be pointed out at this time that these changes could not be incorporated in the San Antonio installation because it was already under construction when this study was completed.

A relative cost comparison was made of three alternative designs for the Texarkana interchange. The results of this comparison are given in Table 2. This comparison is made on the basis of average "per unit" costs, including luminaire, lamp, ballast, support hardware, conductor, and labor rather than detailed costs of each because of the high fluctuation of detailed costs when included as part of an overall contract. This comparison indicates a considerable saving in the use of high-mast lighting as compared to the alternate designs. However, the reader should bear in mind the recommendation that closer spacings should be used, and further, that the interchange under study was a "limited area" cloverleaf, with operating speeds somewhat lower than would be permitted in newer design.

TABLE 2

Design A: High-mast lighting consisting of 5 towers as installed.
Design B: 1000-watt Type III mercury vapor luminaires, 50-foot mounting height, 300-foot longitudinal spacings.
Design C: 400-watt, Type III mercury vapor luminaires, 40-foot mounting height, 200-foot longitudinal spacings.

INSTALLATION COSTS

Design	Wattage	No.	Type	Mounting Height	Spacing	Cost
A	1000	1	10 floodlights	150'		$29,000 (actual)
		4	6 floodlights	100'	>1000'	
B	1000	54	Type III	50'	300'	49,000*
C	400	70	Type III	40'	200'	58,000*

*Estimated cost based on cost per unit price experience by Texas Highway Department.

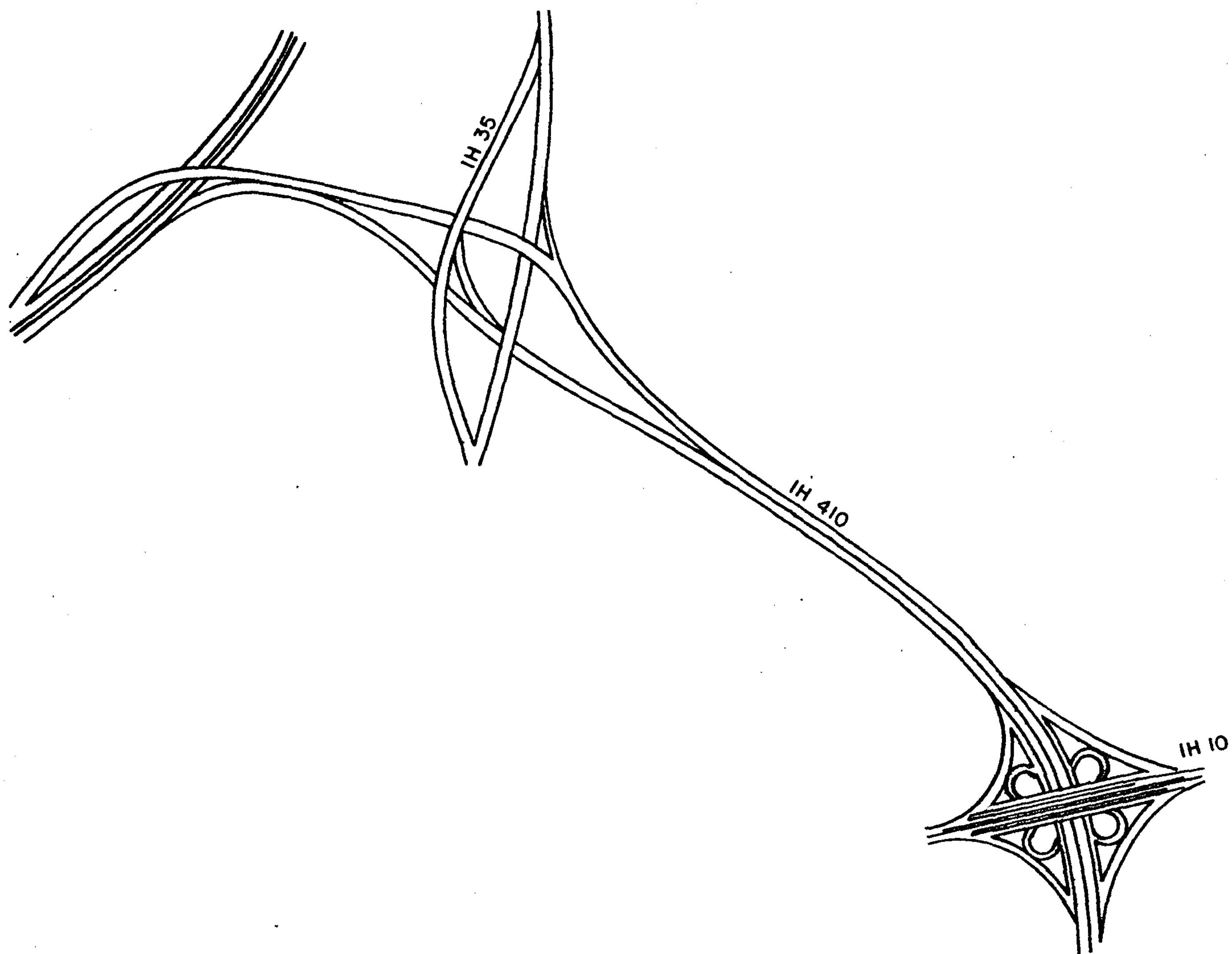
MAINTENANCE AND OPERATION COSTS

Design	Total Units	Wattage	Annual Costs
A	34	1000	No data
B	54	1000	$3,780*
C	70	400	2,800*

*Maintenance and operation cost derived by using a cost of $40.00 per year for 400-watt and $70.00 per year for 1000-watt luminaires as experienced by Texas Highway Department.

San Antonio Study

The San Antonio study site was a complex interchange of I 10, I 410 and I 35, a combination of cloverleaf with collector-distributor roads and two directional type interchanges as shown in Figure 4. Twenty 100-foot high-mast units were used in the interchanges, some with a full complement of ten 1000-watt mercury vapor floodlights, and the remainder with six



San Antonio Study Site

FIGURE 4

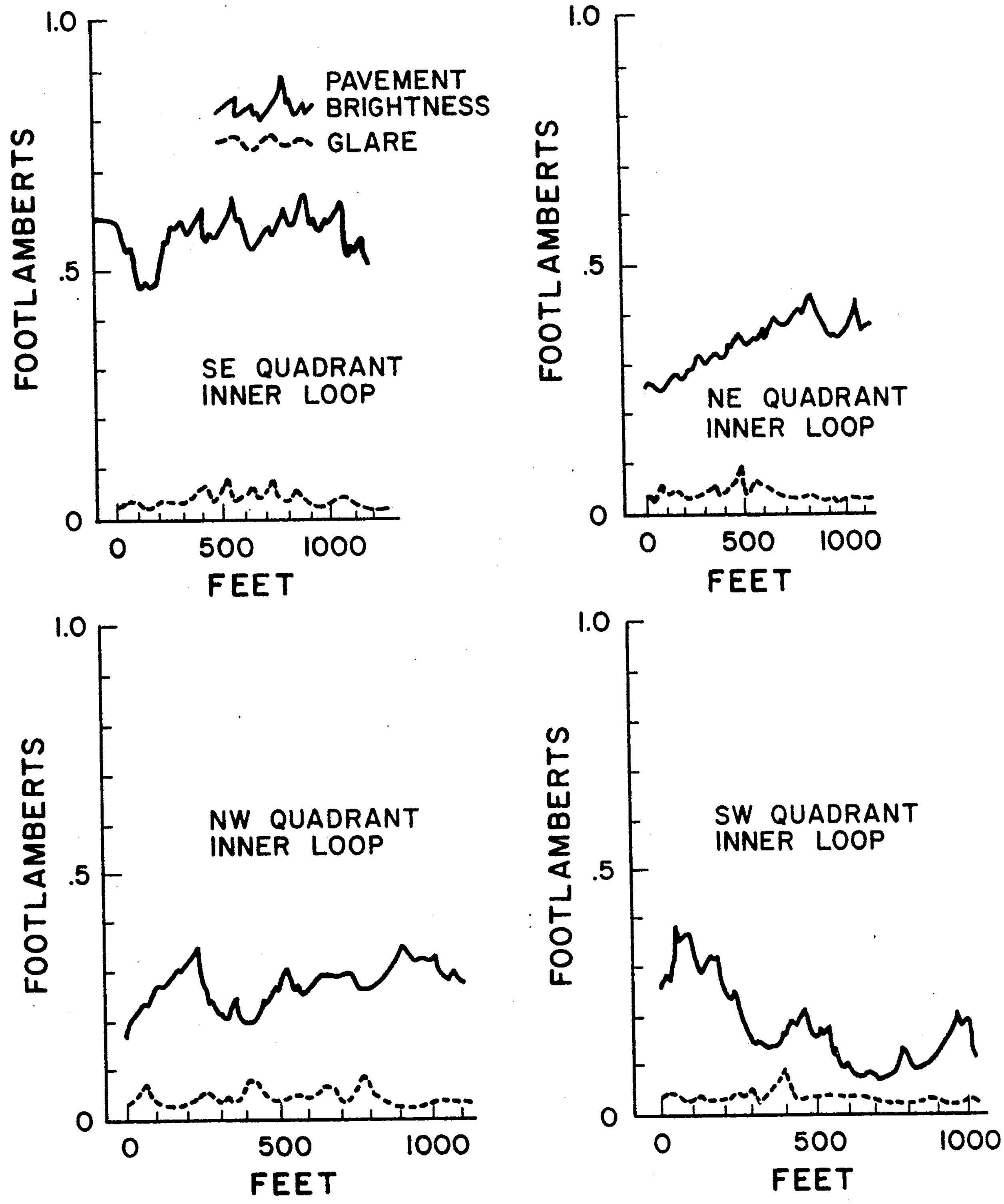
floodlights per mast. Connecting roadways were lighted with 1000-watt mercury vapor luminaires, dual mounted in the median at 50-foot mounting heights spaced at 300 feet. One approach to the interchange was lighted with 400-watt mercury vapor luminaires side-mounted at 30-foot mounting heights and spaced at 160 feet. Typical pavement brightness and glare data for the high-mast lighted areas are shown in Figure 5.

An evaluation team of twenty professionals of various disciplines, including design, operation, maintenance, research, administration and manufacturing was used to evaluate the different techniques of lighting used in the large interchange area and the connecting roadways. The study was conducted in two phases representing generally "dark" and "lighted" conditions. The section of 400-watt lighting was an older system and could not be turned off easily. Therefore, the 400-watt system was energized during both phases of the study.

Each team member made his evaluation during and after driving a 33-mile route through the interchange area and riding as a passenger on two additional trips through the interchange. Data and comments were collected using questionnaires, one to be completed after each of the two phases of the study. The questionnaire forms, with a summary of the results are presented in Appendix A.

The results of the first phase of the study, with only the 400-watt side-mounted units energized, are summarized from the comments on the questionnaires:

1) Dark freeway conditions result in a very insecure and lost feeling.
2) Decision points cannot be identified in adequate time to make required maneuvers safely and efficiently.



PAVEMENT BRIGHTNESS AND GLARE PROFILE

San Antonio

FIGURE 5

3) There is a feeling of tension that leads to greatly reduced speeds and very often missed turns and maneuvers.

4) In the lighted section there was a more relaxed and comfortable feeling.

5) In the lighted section decision points were easier to identify and higher speeds were possible.

5) It was also possible in the lighted section to determine roadway geometry which produced a very comfortable environment.

The results of the second phase of the study, with the full system energized, are summarized as follows:

1) High-mast lighting is definitely superior to other types of lighting for interchange areas.

2) Distances are easier to judge with high-mast lighting.

3) High-mast lighting provided the greatest level of driver comfort.

4) Uniformity of illumination was recognized as the most important quality of the system, with glare and intensity level rated important.

5) Glare was recognized as a minor problem, particularly in the directional interchange area. Spacing of masts should be reduced to permit lower aiming angles of individual floodlights, thus reducing glare effects.

6) The location of certain masts put the light source in the direct line of sight of the driver, and caused some conflicts with overhead signs. Careful attention should be given to the location of masts to avoid conflict with overhead signs, and to reduce glare.

7) Mounting heights should be increased to 150 feet to reduce glare and improve uniformity.

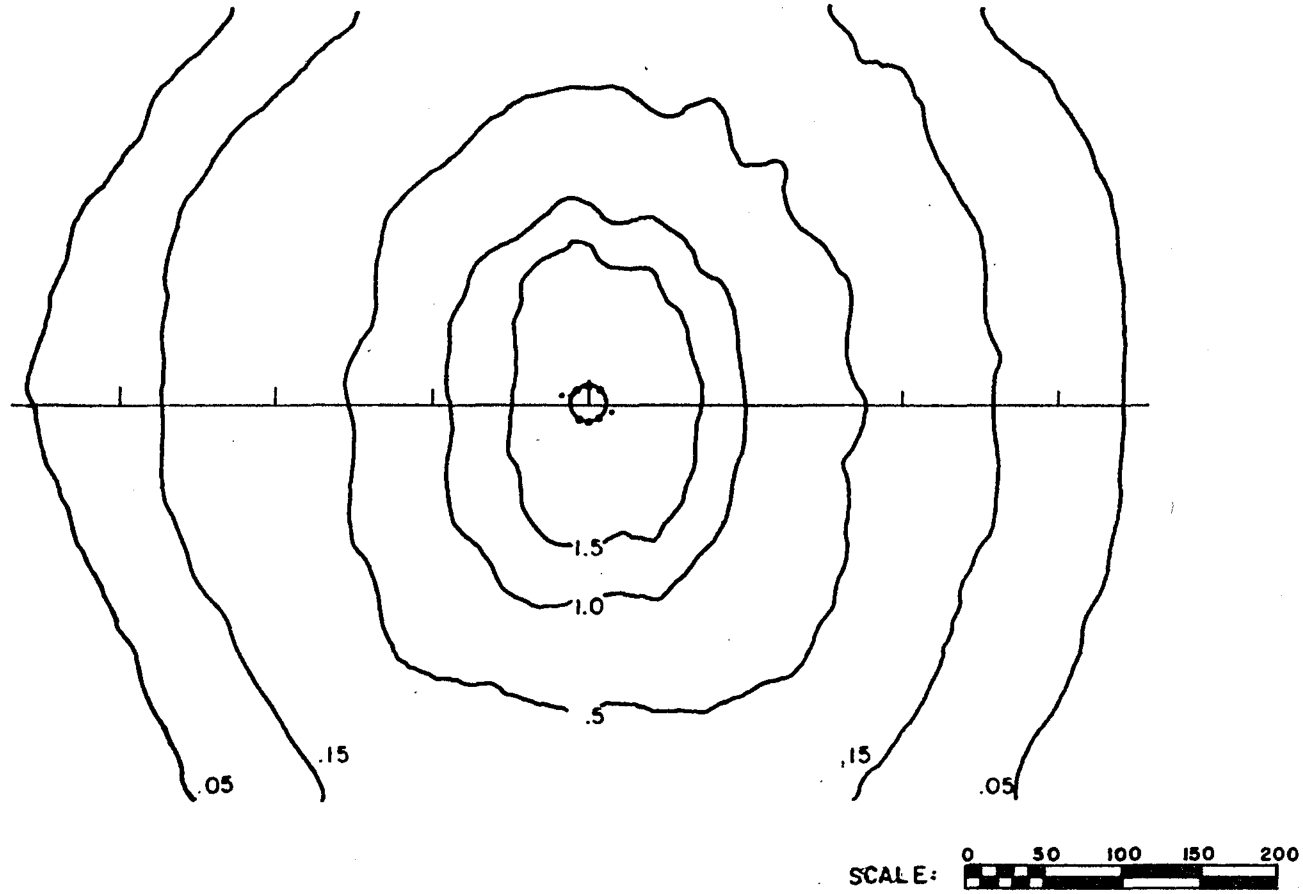
8) The median mounted system was judged very good, but spacing should be reduced to 250 feet. The "area lighting" effect (spread of light into adjacent areas and frontage roads) was desirable but it was recommended that supplemental lighting be provided at ramps.

9) The side-mounted system was judged inadequate. Recommendations were made for increased mounting heights, more light, and "spill-over" to frontage roads.

Comparison of Floodlight System with IES Type V Luminaire

As mentioned earlier, a system of high-mast lighting was installed in the Auburn interchange near Seattle, Washington, concurrent with the Texarkana and San Antonio installations. The Auburn installation utilized a prototype Type V luminaire with metal halide lamp to provide a circular distribution. Subsequent to their use in the Auburn interchange, Type V luminaires were obtained for test and evaluation at the Texas A&M Research Annex Outdoor Lighting Facility. Measurements of light distribution were made for combinations of 4, 6, and 8 units of Type V luminaires mounted at 150 feet. Measurements were made for both 1000-watt mercury and metal halide lamps in the fixtures. The results are illustrated in Figure 6, an iso-footcandle diagram for a system of 8 luminaires with a 9-inch light center setting.

The Type V luminaire has provisions for changing the light center spacing relative to the reflector assembly. Changing the location of the light center changes the distribution of light from the luminaire. The manufacturer recommends 7, 8, and 9-inch spacings which provide 55°, 59° and 63°, respectively, for angle from nadir for maximum candlepower.



ISO-FOOTCANDLE CURVE
EIGHT 1000 WATT IES TYPE V

HEIGHT: 150'
9 INCH LIGHT CENTER

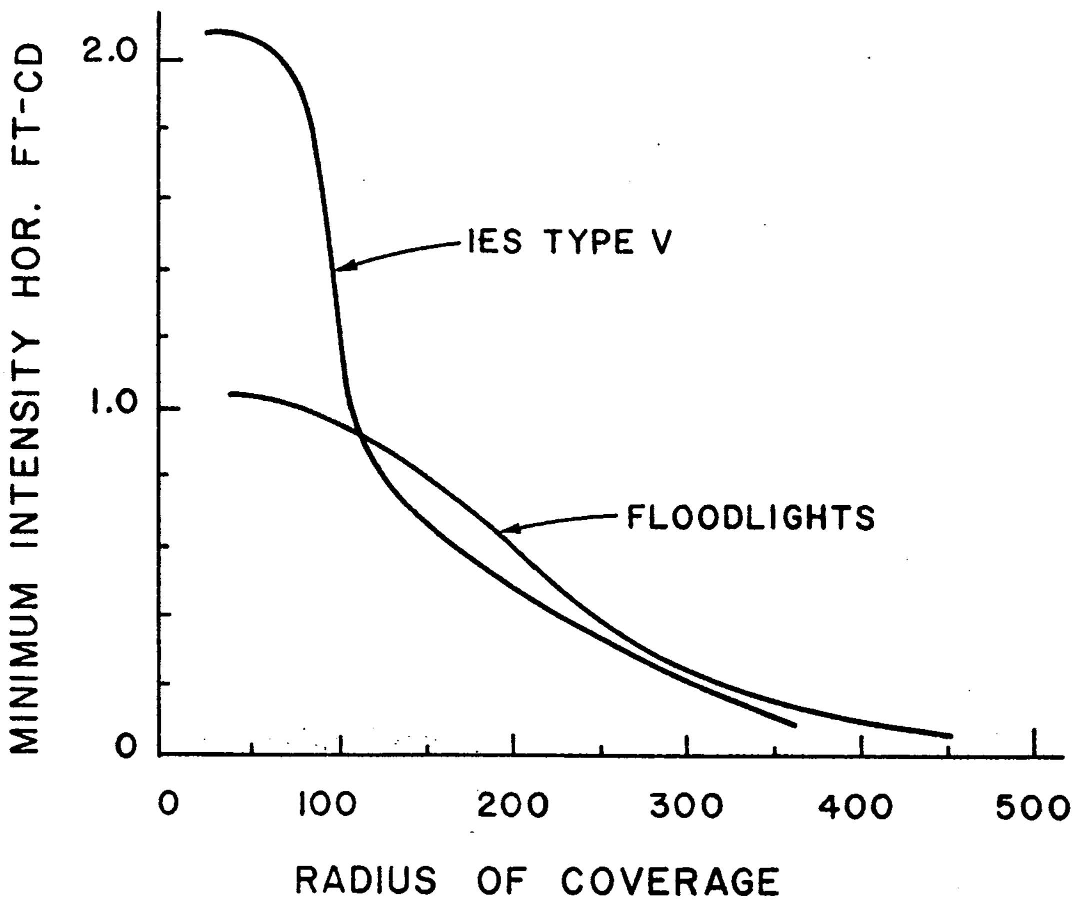
FIGURE 6

A comparison is made of the two types of lighting equipment, based on observations and measurements at the research facility, observations at the Auburn interchange, and at a newly-completed interchange lighting installation near Seattle.

A photometric comparison of the two systems is provided in Figure 7, where a radial profile of the circular distribution of each light system is shown. The floodlights, ten units spaced 36° apart, are aimed at 45° with the vertical. The Type V luminaires, 8 units, are adjusted to the 9-inch light center spacing. It is noted that a more uniform distribution is provided by the floodlight system, and for a given minimum level of illumination, the Type V luminaire system must be spaced more closely than the floodlight system.

The floodlight system is much less critical in spacing of masts because of the flexibility provided in the aiming capability of the floodlights. With the Type V system, once the location of the mast is established, the light distribution is fixed, except for the adjustment in light center spacing. This makes it more difficult to control the uniformity of illumination on the roadway.

The Type V luminaire system provides the advantage of "redundancy" in light sources. A "burn-out" of one light source results in an overall reduction in illumination rather than leaving a "hole" in the distribution. The floodlight system has a similar characteristic because of the overlapping of patterns from adjacent units, but is less effective because it lacks complete redundancy. Because of the complete redundancy, the Type V system permits greater flexibility in scheduling maintenance of the system.



PHOTOMETRIC COMPARISON
of
Eight 1000-watt IES Type V Luminaires
Equipped with Multi-Vapor Lamps
and
Ten 1000-watt Floodlights
Equipped with Clear Mercury Lamps

FIGURE 7

It should be noted that the two interchanges near Seattle have utilized three luminaires per mast with a mounting height of approximately 100 feet. An installation of the units at higher mounting heights is needed to provide a more reliable comparison.

The designer using the Type V luminaire cannot meet the uniformity requirements as recommended in this report without exceeding the average illumination significantly. On the other hand, a significant increase in the average illumination level will permit a relaxation in the uniformity ratio. In no case, however, should the uniformity ratio be greater than recommended by AASHO for conventional lighting.

RECOMMENDATIONS FOR IMPLEMENTATION

The research and developmental work at the Texas A&M Research Annex Outdoor Lighting Facility and the full-scale experimental installations at Texarkana and San Antonio, and in other states, as well, have provided a great amount of information on the application of the high-mast lighting concept in interchange areas. This section of the report presents tentative guidelines and recommendations for implementation, with the expectation that early design practice will dictate changes in these guidelines. Although many of the studies on which these recommendations are made were subjective in nature, these guidelines can be presented with the confidence that the underlying subjective evaluations were made by professional people with extensive experience in various highway related disciplines.

Design values given in these guidelines should be treated as minimum values, and should be used only where "conditions are ideal." The values should be increased proportionately as extenuating circumstances prevail.

1. Average Light Intensity

Acceptable light distributions can be achieved using mounting heights of 100 to 150 feet. However, mounting heights of 150 feet provide a better distribution and aid in the control of glare. The high-mast installations in Texas and South Dakota (8) have provided average intensities of 0.25 to 0.35 horizontal footcandles. In general, the evaluations have shown that little additional illumination is needed. On the other hand AASHO recommends a minimum average intensity of 0.6 horizontal footcandles (9) for continuous freeway or interchange lighting with a uniformity ratio as great as 4:1, average to minimum. By controlling the uniformity ratio more rigidly, it is felt that a lower average intensity can be utilized to achieve equivalent visibility conditions. Hence, the following recommendation is made:

Average Intensity: 0.5 hor. ft-c.

For areas other than roadway surfaces the average intensities should equal or exceed 0.10 hor. ft-c.

These values should be increased accordingly as any of the following extenuating circumstances prevail:

a. If high average intensity is maintained on any connecting roadway. There is no positive rule, but the average intensity of illumination on roadways in the interchanges should be at least one-half and preferably two-thirds that on the connecting roadway.

b. If there is a relaxation in the uniformity requirements given below, and the average intensity in the interchange is no better than the connecting roadway, then the average intensity in the interchange should at least equal that on the connecting roadway.

c. If there is (or expected to be) competitive lighting from adjacent development, the light levels in the interchange should be increased accordingly. Once again, there is no positive rule, but it should be recognized that lighting effects are relative, and a brightly lighted adjacent area will make a normally good lighting installation completely inadequate. On this basis, roadway lighting should be made competitive.

2. Horizontal Illumination

The horizontal component of light is recognized as an asset to interchange lighting. On the other hand, it can produce objectionable glare effects. For the best effect, horizontal illumination should be maintained in good balance with the normally specified vertical component. It is possible to specify the average vertical footcandle level at about 75% of the horizontal footcandle level, but the most practical approach to maintaining this balance is to control the spacing to moderate proportions while achieving the desired average intensities and uniformity ratios specified herein. On this basis, the spacing to mounting height ratios should fall within the range of 3:1 to 5:1.

3. Uniformity of Illumination

The uniformity of illumination is recognized by most roadway lighting engineers as being the most important characteristic of the lighting system. The ratio of average to minimum intensity has been used as the descriptor of uniformity, but many feel that the ratio of maximum to mimimum intensity best describes the uniformity as it influences visibility. Both ratios are given below:

Uniformity of illumination on the roadway:

Average to minimum ratio: 2 to 1

Maximum to minimum ratio: 4 to 1

4. Glare Control

In addition to methods previously discussed, it is envisioned that glare can be controlled sufficiently by relying on the guide set forth in the ASA Standard, "American Standard Practice for Roadway Lighting," (10) which describes the control of candlepower distribution for luminaires normally used for roadway lighting. High-mast lighting should not be treated differently than the semi-cut-off luminaires normally used in roadway lighting.

5. Placement of Masts

The masts should be located as far as practicable from the travel lanes to reduce the fixed object hazard potential and to minimize the effect of glare. Also, there is an optimum location of the mast relative to the roadway to provide the most uniform light level on the roadway. In addition, careful consideration should be given to placement of the mast to assure that the light source is not directly in the line of sight of the driver.

6. High-Mast Supports

Both poles and towers have been used on high-mast lighting installations with apparently equal functional capability. Manufacturers now offer both as a "package deal," including lowering assemblies and other mounting hardware. The decision as to which type to use is a decision of local influence and should not be relegated to guidelines and practices.

7. Mounting Assemblies

There are three basic methods available for mounting high-mast light sources, described as follows:

a. Light sources fixed at top of mast; provisions are made for climbing the mast for service and maintenance.

b. Light sources fixed at top of mast; provisions are made for a motorized personnel carrier to transport service man to light sources for service and maintenance.

c. Light sources mounted on a lowering assembly with a motorized winch to facilitate lowering and raising of lighting assembly for service and maintenance. There are several versions of this latter method available. Some have locking mechanisms and power connections at the to   ıile others provide continuous cable suspension for the lighting assembly and a continuous power supply line, connected at the base.

again, the selection of the method of mounting is largely dependent local influences and preferences.

DESIGN CONSIDERATIONS

Most experienced lighting designers have their own established design procedure, and it should be adaptable to the design of the high-mast lighting. For those that do not have an established procedure, the research staff has developed a procedure, which is included as Appendix B.

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APPENDIX A

HIGH-LEVEL ILLUMINATION

DIAGNOSTIC STUDY QUESTIONNAIRE

PART A

PROJECT 2-8-64-75

IH 10 - IH LOOP 410 SAN ANTONIO, TEXAS

NAME ______ SUMMARY ______________

AFFILIATION ______________________

____

____

PART A

Questions in this part apply to an evaluation of the study area as it existed prior to the high-level illumination construction project.

Please answer all questions by checking the appropriate box. Space is provided for any comment you may have on any question.

Note: Number in box indicates the number of team members checking that box.

1. Did you feel roadway markings were more noticeable with or without continuous roadway illumination?

   /10/ more noticeable with illumination

   / 1/ more noticeable without illumination

   / 5/ no noticeable differences

   Comment: Fairly good both. Depends on condition of roadway Very difficult to see gore markings both. More noticeable without especially pavement markings. Exception, wet pavement. Need edge striping regardless. Definitely improved with lighting.

2. Which of the conditions provided the most desirable visibility of ground-mounted roadway signs?

   /13/ with illumination

   / 1/ without illumination

   / 2/ no noticeable differences

   Do you feel repositioning any luminaires with respect to sign placement would affect your answer above?

Yes /8/ No /8/

Comment: Signs need attention. No difference. Those placed in front of exit signs good. Need more ramp lighting for guidance signs. Continuous lighting reduces button brightness on signs. Particularly at merging signs

3. After having driven through four lighting transition areas, do you feel it is important that transition areas be located on tangent sections to allow sufficient eye adaptation time before the driver is required to negotiate alinement changes?

Yes /14/ No /2/

Comment: Very definitely. Don't know where you are when leaving lights. Can't see. Let eye adapt only when going from light to dark. Provided glare not too high, especially after driving long time in lighted section.

4. In the section without continuous illumination, which of the answers below best describes your evaluation of the visibility of geometric features of the roadway such as curves, structures etc.?

/12/ visibility is below minimum acceptable level for high-speed facility

/3/ minimum visibility requirements of normally alert drivers is satisfied

/ / visibility is adequate for most drivers

In the area of continuous illumination, do you feel there is a significant increase in visibility of geometric features?

Yes /15/ No /1/ No Significant Difference / /

Comment: Need shoulder contrast. Ramp noses need better delineation. Type IV Delineator inadequate. Standards serve as delineators. Not noticed. Definitely. Can't drive posted speed in dark.

5. Check all of the below conditions in which you feel most drivers would have sufficient visibility to recognize a major obstacle (such as a stalled unlighted vehicle) in the roadway in time to allow drivers to come to a safe stop. (Transition area is considered to be the area in which your eye is not fully adapted to new illumination condition.)

/16/ continuous illuminated section

/ 2/ transition area from illuminated section to non-illuminated section

/ 2/ non-illuminated section

/ 9/ transition area from non-illuminated section to illuminated section

Comment: Reflectors on stalled vehicle would mean a lot. Definitely best in 50' section.

6. Do you feel the existing roadway delineation systems are more effective with continuous illumination or without illumination?

/15/ more effective with illumination

/ 3/ no difference in effectiveness

/ 8/ more effective without illumination

Comment: Not effective at all. Dead delineators. Delineation more effective with illum. Less without, however, they are less important then. Delineators definitely needed on unlighted sections. No difference. Headlights provide key.

7. In the area with no illumination, how accurate are you able to judge speeds and distances to other vehicles?

/ 0/ as well as in daylight for all distances

/ 2/ as well as in daylight for short distances only

/ 8/ not as well as in daylight at any time

/ 9/ speed judgment of other vehicle is severely restricted at night

Do you feel continuous illumination increases the accuracy of speed and distance judgments?

Yes /14/ No / 1/ No Change / 1/

Comment: Seeing pavement between you and other vehicles help. Can see entire vehicle moving rather than lights. Speed must be reduced to have same effect in dark. During merge especially. Especially speed. Yes, by reflecting light off of moving vehicles.

8. In driving in the section with no illumination, were you able to detect all the information you desired about the shoulder area and elsewhere in the right-of-way?

/ 1/ in most instances, this was possible

/ 7/ about half of the time

/ 8/ only infrequently

In the area with continuous illumination was the visibility of the shoulder area and beyond improved significantly?

Yes /14/ No / 1/ No Change / 1/

Comment: Could still be improved. Need better contrast. Still have hard time finding ramp noses, road not well delineated.

9. Describe briefly the differences you feel exist in following your route through a non-illuminated interchange and illuminated interchange.

Decision points easier to locate with lighting. More time with lighting. Feel lost in dark. Can't find decision points. Need edge striping regardless. Feel confident with light. Tense in dark. Easy to miss turn in dark. Have to drive slow in dark. More comfortable under lights. Sense of uncertainty in dark. High speed on illuminated sections. Can't determine geometry in dark.

10. Under which of the conditions was headlight glare from opposing traffic more noticeable?

/ 0/ headlight glare more noticeable with illumination

/10/ headlight glare more noticeable without illumination

/ 6/ did not notice any differences in headlight glare

Comment: Didn't notice. More without illumination. Never objectionable. Separation sufficient. Very definite without.

11. Were you able to determine the location of deceleration lanes and gore area more readily without illumination?

Yes / 0/ No /15/ About the Same / 1/

Comment: Gore area not visible at all. Didn't know where to start maneuver. Post delineators didn't help. Need edge striping. Expecially on non-tangent sections.

12. Under which of the conditions did you feel more secure in exiting from the freeway?

/14/ with illumination

/ 0/ without illumination

/ 2/ no noticeable difference

Comment: With illumination. Much easier to see ramps. So nice to see more than pavement ahead.

13. While riding as a passenger through the route, did other drivers in your vehicle seem to begin decelerating sooner when exiting from freeway in unlighted area or have to make a sudden or sharp turn to exit on unlighted ramps?

Yes /15/ No / 0/ No Difference / 1/

14. How would you best describe the difference in driving due to continuous illumination of the roadway?

/14/ major increase in visibility and significant reduction in necessary sudden movements and rapid decelerations

/ 1/ major increase in visibility, but no change in vehicle operation

/ 1/ slight increase in visibility, but not sufficient to be of benefit to most drivers

/ 0/ no change in overall driver visibility

/ 0/ prefer to drive in non-illuminated section

Comment: Being able to see more objects. More comfort. Confident. Reduction in speed on non-illuminated sections. Lighting cannot completely overcome geometric blunders.

15. Does pavement surface affect the effectiveness of continuous illumination systems?

Yes /13/ No / 3/

Comment: Asphalt absorbs too much light. Asphalt too spotty. Didn't notice any difference. Concrete much better. About the same. Considerable difference.

16. What effect does pavement surface have on overall visibility?
Rough surface doesn't reflect too good. Smooth concrete better. Concrete much better. Very little effect. None, Dark pavement reduces visibility. PCC better.

17. List any other feature which you consider to be major difference in a non-illuminated roadway and a continuously illuminated roadway not covered by this questionnaire.
Can't recognize geometry. Can't associate with other roadways feeling of being in control under lighting. Delineators actually confusing without lighting. More security under light. The ease of driving in lighting system. Being able to see ahead. Driver awareness of surroundings. Forest of poles only objection to continuous lighting. Lighting reduces effect of extraneous sources in environment such as cafes, etc. Lighting reduces sudden maneuvers which are dangerous. Definitely improves comfort. These conditions bad even in daylight.

HIGH-LEVEL ILLUMINATION

DIAGNOSTIC STUDY QUESTIONNAIRE

PART B

PROJECT 2-8-64-75

IH 10 - IH LOOP 410 SAN ANTONIO, TEXAS

NAME Summary

AFFILIATION

PART B

The questions in this part apply to an evaluation of various types of roadway illumination. For the purposes of these questions, the lower numbers represent the most desirable condtions. Please rate all illumination conditions where requested. Space is provided for any comments you may have regarding any question.

Note: Best possible score is 18. Worse possible score is 54.

1. How do you rate the visibility of roadway markings under the various illumination conditions?

(a) Main Lanes		(b) Frontage Road & Ramps	
/28/	Center-Mounted Continuous	/31/	Center-Mounted Continuous
/48/	Side-Mounted Continuous	/47/	Side-Mounted Continuous
/27/	High Level	/25/	High Level

Comments: Center-mounted spill light good on Frontage Roads condition of markings had effect. Side-mounted no help at all on Frontage Roads.

2. How do you rate the visibility or roadway signs under the various illumination conditions?

(a) Main Lanes		(b) Frontage Road & Ramps	
/28/	Center-Mounted Continuous	/32/	Center-Mounted Continuous
/49/	Side-Mounted Continuous	/51/	Side-Mounted Continuous
/27/	High Level	/22/	High Level

Comments: Signs need attention. Move lights from behind signs. Lighting does not help sign visibility. High-level gives better contrast. Not much affect High-level definitely better.

3. How do you rate the visibility of, or the ability to distinguish, geometric design features (such as curves, structures, etc.) under the various illumination conditions?

(a) Main Lanes

/33/ Center-Mounted Continuous

/19/ Side-Mounted Continuous

/19/ High Level

(b) Frontage Roads & Ramps

/34/ Center-Mounted Continuous

/53/ Side-Mounted Continuous

/21/ High Level

Comments: High-level very superior. Reveals entire scene. High-level very impressive. Some evidence of excessive brightness with high-level ramps hard to locate with conventional.

4. Under which illumination condition do you feel most confident in evaluating distances, and speeds of other vehicles?

(a) Main Lanes

/34/ Center-Mounted Continuous

/55/ Side-Mounted Continuous

/25/ High Level

(b) Frontage Roads & Ramps

/37/ Center-Mounted Continuous

/50/ Side-Mounted Continuous

/22/ High Level

Comments: About same. High-level much better.

5. Which illumination condition produces less noticeable differences in visibility between the various traffic lanes?

/35/ Center-Mounted Continuous

/52/ Side-Mounted Continuous

/29/ High Level

Comments: Better gradients with high-level. Not much difference in center-mounted and high-level. Too many striations in conventional. High-level better transverse and longitudinal. All very close.

6. Under which lighting conditions do you feel most comfortable for continuous main lane travel?

/29/ Center-Mounted Continuous

/48/ Side-Mounted Continuous

/23/ High Level

Comments: High-level very superior. Too much ladder on others. Side-Mounted very poor. High-level to glarey. Side-mounted to non-uniform. High-level great even for 70 mph. With high-level no boxed-in feeling.

7. Of the following factors generally conceded to be important in illumination systems, how would you rate their importance in your decisions on questions 1 - 5?

Note: Best score possible for most important is 18. Best score possible for least important is 90. The lower score indicates greater importance.

/30/ Uniformity of illumination

/55/ Level of Illumination

/61/ Area of Coverage

/55/ Glare Characteristics

/86/ Others Safety, economy

Comments: Should be combination of all four. Uniformity and glare prime factors.

8. Under which lighting conditions do you feel most comfortable in entering main lane traffic?

/35/ Center-Mounted Continuous /21/ High Level

/49/ Side-Mounted Continuous

9. Under which lighting conditions do you feel most comfortable in exiting from main lane traffic?

/31/ Center-Mounted Continuous

/45/ Side-Mounted Continuous

/19/ High Level

Comments: Tower in line of sight needs moving. Is source of discomfort. Center-mounted and high-level very close. High-level better.

10. Do you feel that repositioning of luminaires would affect your rating on questions 6 and 7?

Yes /11/ No /9 /

If so, how? Side-mounted could be higher if placed in ramp areas. Some towers could be repositioned. Need exit ramp lighting with center-mounted. Improve ramp lighting. Use staggard arrangement. Only be higher heights.

11. How do you rate the effectiveness of the existing roadway delineation under the various illumination conditions?

/31/ Center-Mounted Continuous

/41/ Side-Mounted Continuous

/24/ High Level

Comments: Delineation no good to begin with. Delineation inadequate to start. Edge marking needed. Illumination can't correct problem. No difference.

12. Under which lighting condition is opposing headlight glare least noticeable? (Lowest numbers for least noticeable.)

/26/ Center-Mounted Continuous

/41/ Side-Mounted Continuous

/28/ High Level

Comments: Educated guess. Didn't really notice. Least noticeable when system glare greatest. No difference. Not noticeable. No problem. Conventional better. Depends on headlight barrier.

13. Under which lighting condition is glare from luminaires least noticeable?

/27/ Center-Mounted Continuous

/39/ Side-Mounted Continuous

/37/ High Level

Comments: High-level could be better through adjustment. Lower angle. Remove from line of sight.

14. Do you feel there is any advantage to illuminating areas other than the roadway surfaces only, in interchange areas?

Yes /19/ No / 1/

Give a brief explanation: Orientation of driver. See geometry Removes tension. Creates assurance. Better visual cues. Better guidance. Less eye fatigue. Need overall picture. Forewarned is forearmed. Know where you are. Get the "feel." Early observation possible. Determine directions in advance. Easy to locate signs. Plan movements ahead. Awareness of traffic flow. Doubtful of its worth. Removes tunnel effect.

15. Which illumination condition most nearly duplicated daytime visibility as regarding driving tasks? (lowest numbers indicate closer duplication).

/32/ Center-Mounted Continuous

/39/ Side-Mounted Continuous

/20/ High Level

Comments: High-level definitely superior, very good panoramic concept of features.

16. How do you rate your overall driving comfort for the various illumination conditions? (Lowest numbers indicated greatest comfort).

/34/ Center-Mounted Continuous

/51/ Side-Mounted Continuous

/21/ High Level

Comments: Glare objectionable all 3 in some cases. High-level could be better through positioning. High-level almost as good as day driving. Center-mounted better.

17. Do you feel that your rating in question 14 would be affected by modification of any of the systems?

Yes /11/ No / 9/

Give a brief explanation: IH 410-Loop 13 needs one or two additional Towers to lower aiming angle. Cloverleaf very good Better uniformity on conventional may increase their rating. Adjust aiming on towers; better still. No way to match high-level comfort. Need 150' height on high level.

18. What improvements do you feel could be made in either system that would increase your overall driving comfort and safety?

(a) Side-mounted continuous Additional lights in ramp area. Increase heights. Use doubles at ramp. Don't use period. Eliminate hot spots. Need spill light to frontage roads forget them.

(b) Center-mounted continuous Better uniformity by spacing closer. Remove striations. Limit spacing to 250'. Eliminate hot spots. Build more just like it. Increase height to 60'. More light on ramps.

(c) High level Reduce glare. Move out of line of sight. Space closer. Limit spacing/mounting height ratio to 6:1. Add some towers. Increase height to 150'.

19. Please indicate which, if any, of the transitional situations caused any noticeable transition or adaption problems.

None with high-level. Very good. Some with conventional when leaving lighted section. Leaving side mounting and into dark frontage roads. Nothing serious on any. None. Fringe areas in high-level washout. Transition good.

20. Please list and briefly discuss other factors of the three types of illumination system you feel should be considered in the evaluation of the systems.

Safety, cost, aesthetics, spilled light outside of right of way. Should consider Type V distribution. Compare under adverse weather; rain, snow and fog. Definitely need to exam tower locations. Need 150' heights.

APPENDIX B

SUGGESTED DESIGN PROCEDURE
FOR HIGH-MAST LIGHTING

This design procedure was developed on the basis of floodlight performance data developed in this research project. The procedure employs iso-footcandle transparencies for floodlight systems or Type V Luminaires. The transparencies can be obtained from the Texas Highway Department or the Texas Transportation Institute.

One may construct approximate iso-footcandle curves for the two different types of lighting systems using the data given in Table 1B. Also, the data in Table 1B can be used to draw iso-footcandle curves (circles) directly on the trial plan sheet. Where the circles overlap, add the quantities and readjust the contour lines.

In using this design procedure, the designer must use the job specifications to insure that the system of floodlights provide the desired distribution characteristics. It is suggested that the specifications be written to include the data from Table 1B for the system selected for design.

Step 1. Establish the desired average level of illumination. The basic value is 0.5 hor. ft-cd. and adjustments should be made as follows:

a. Check the average illumination on each leg of the interchange, (current or planned for the future). Average illumination for the interchange should be at least ½ and preferably 2/3 that on any leg of the interchange.

b. Check the land usage in close proximity to the interchange for current and future developmental lighting. This is difficult to predict and even more difficult to provide compensation in the design. The best guide is to observe the adequacy of other lighting systems in the general vicinity with prevailing developmental conditions similar to conditions anticipated in the design and adjust the average illumination accordingly.

Step 2. Establish the desired minimum level of illumination on the roadway. The basic value is 0.25 hor. ft-c. This value should be adjusted upward in accordance with adjustments made in Step 1.

Step 3. Establish the desired maximum to minimum ratio for the roadway. A 4:1 ratio is recommended; however, this can be increased if the average illumination is increased accordingly.

Step 4. Determine the maximum spacing of supports to meet the average illumination requirements (see Figure 1B). Do not use more than 5:1 S/MH ratio,

Step 5. Determine the maximum spacing of supports to meet the mimimum illumination requirements.(See Figure 2B) Do not use more than 5:1 S/MH ratio.

Step 6. Determine the distance of the mast from the roadway to achieve the desirable maximum and minimum values. This is a helpful guide in locating masts with respect to the roadway.

Step 7. Locate the masts on an overlay on the plan sheet so that the highest intensities are at conflict points or major maneuver points. Locations can be checked and adjusted using a transparency of the iso-footcandle curve. There are several points on mast location that should be checked at this stage. If a model of the interchange is available, it would be of great value in checking locations.

However, a thorough study of plan and profile of roadways and mast position and elevation is generally adequate to check the following:

A. Masts should be located so that the highest levels of illumination are in the areas of greatest informational needs, such as geometric changes and traffic conflicts.

B. Masts should not be located in gores, at the beginning of sharp curves or other locations where there is a relatively high probability of an out-of-control vehicle.

C. Masts should not be located in the direct line of sight of drivers on the roadway, especially in a range of 500 to 1500 feet from the mast. Consideration should be given to grades and elevations relative to the light source.

D. Masts should be co-ordinated with signing to insure that the light source is not directly behind the signs at a critical point.

E. Transitional effects should be considered on unlighted approaches to the interchange. With floodlight systems, it is desirable to use a partial system of floodlights in the transition and direct the lighting across the roadway and into the interchange area.

Step 8. Plot an iso-footcandle curve for the interchange using the transparency or appropriate data from Table 1B. Then determine the maximum, minimum and average illumination on each of the roadways.

Compute necessary ratios and check against established criteria. Check minimum values in non-traffic areas against established criteria.

TABLE 1B

RADIAL DISTANCES, FROM LIGHT SUPPORT FOR INDICATED HORIZONTAL FOOTCANDLE INTENSITIES, TO BE USED FOR SPECIFICATIONS AND FOR CONSTRUCTING ISO-FOOTCANDLE CONTOURS.

	FLOODLIGHTS*				TYPE V DISTRIBUTION**					
Intensity Contour Hor.Ft-CD	45 Degree Aiming Angle 10-1000W				8" Light Center			9" Light Center		
					4-1000W	6-1000W	8-1000W	4-1000W	6-1000W	8-1000W
	100' MH	120' MH	140' MH	150' MH	150' MH	150' MH	150' MH	150' MH	150' MH	150' MH
2.50							50			
2.25							90			
2.00	40						75			80
1.75	60						100			90
1.50	120	40				90	110		80	100
1.25	135	80				100	140		90	110
1.00	140	150	70	70	90	140	180	90	100	120
.90	160	170	160	160	110	150	190	105	115	125
.80	165	175	170	175	115	160	200	110	120	130
.70	170	180	190	190	120	170	210	115	130	180
.60	180	190	200	200	140	190	220	125	140	200
.50	190	210	220	220	180	225	240	140	200	220
.40	210	220	250	250	200	230	250	180	225	250
.30	230	240	290	290	220	240	270	230	260	280
.20	255	280	310	340	240	290	320	260	300	320
.10	310	340	400	440	300	320	350	310	355	360
.05	360	390	500	560	340	360	375	345	365	380

*Equipped with 1000-watt clear mercury vapor lamps.
**Equipped with 1000-watt multi-vapor lamps.

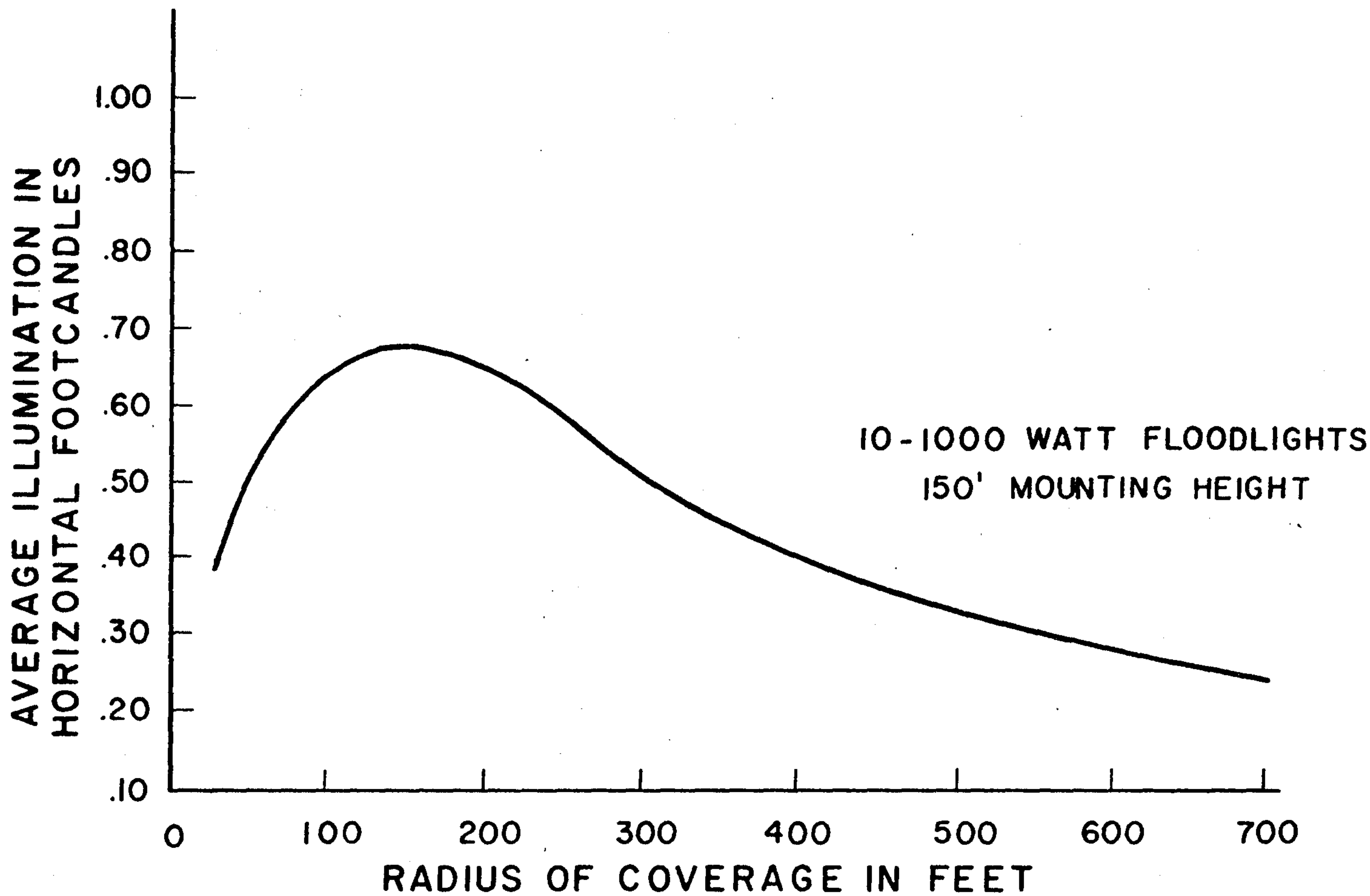
AVERAGE ILLUMINATION IN HORIZONTAL FOOTCANDLES
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
0
100
200
300
400
500
600
700
RADIUS OF COVERAGE IN FEET
10-1000 WATT FLOODLIGHTS
150' MOUNTING HEIGHT

FIGURE 1B

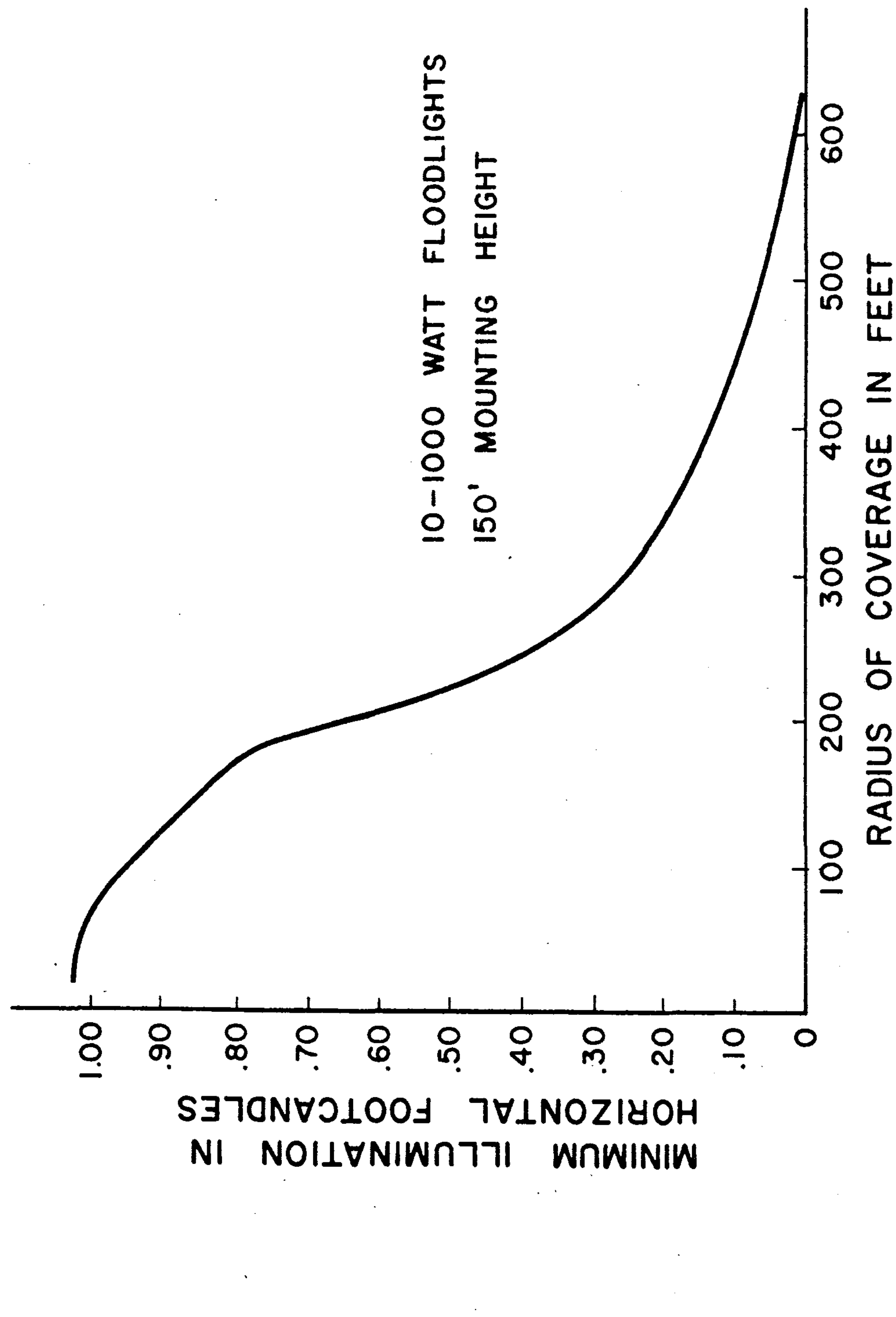
10-1000 WATT FLOODLIGHTS
150' MOUNTING HEIGHT
MINIMUM ILLUMINATION IN HORIZONTAL FOOTCANDLES
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
0
100
200
300
400
500
600
RADIUS OF COVERAGE IN FEET

FIGURE 2B